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Section F. Conference: Chemigation of Insecticides as an Application Technique for Insect Control

December 11, 1984
San Antonio, Texas

Edited by
John R. Young
Research Entomologist
U. S. Department of Agriculture
Agricultural Research Service
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Chemigation is defined as the application of chemicals, such as fertilizers, herbicides, nematicides, fungicides and insecticides, via an irrigation system by injecting the chemical into the water flowing through the system. This method has been shown to be an effective method for controlling insects and is as cost-effective as other methods of application. When incorporated into a management system, which includes all production inputs, it is the most economical method for crop production. The development of chemigation technology, its rapid acceptance by farmers, and the increase in researchers interested in or conducting research on chemigation, stimulated the discussion of the status, principles and future of chemigation through this Conference.

The manuscripts in this proceedings are not scientific treatises on completed research. Rather, they are discussions on the state-of-the-art of research, extension and private enterprise for this rapidly expanding industry.

ROLE OF FORMULATIONS IN THE APPLICATION OF INSECTICIDES THROUGH IRRIGATION SYSTEMS

by

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Chemigation, or the application of chemicals through irrigation systems, has become an accepted management tool by farmers (Threadgill 1984), especially to apply fertilizers (Fischbach 1982). McMaster and Douglas (1976) showed that this method could be used to apply fungicides to potatoes and reported that disease control obtained with chemigation was equal to that obtained with conventional applications. Independently, in the mid-70's, Raun (1981), Young (1980), and Meeks (personal communication) applied insecticides by chemigation to control corn insects. The existing formulations used in the initial studies produced varying but promising results. Young (1980) suggested that an oil formulation might produce consistently good results, and he later confirmed this hypothesis (Young et al. 1981).

Studies have been conducted with many types of irrigation systems (Young et al. 1981, Apt 1981, Gerstl 1981, and Overman 1974). For this presentation, only pesticides applied through center-pivot, overhead sprinkler systems will be discussed.

The first question that must be answered is why use a center-pivot irrigation system for applying pesticides? Threadgill (1984) gave the following advantages of chemigation. Only insect control with reduced rates of

Figure 1. Advantages for using chemigation.

1. Provides excellent uniformity of chemical application
2. Allows prescription application of chemicals
3. Allows timely chemical application
4. Allows easy and effective chemical incorporation and activation
5. Reduces soil compaction
6. Reduces mechanical damage to the crop
7. Reduces operator hazards
8. May reduce chemical requirements
9. May reduce environmental contamination
10. Economical
11. Effective

insecticides when formulated as water-insoluble solutions, the effectiveness of chemigation as a means of controlling insects, and the economics of chemigation will be discussed. The other advantages are more obvious and are discussed by Threadgill (1984).

Potential users are always interested in the cost of any new technology. For insectigation (the application of insecticides in irrigation water), the values given by Threadgill (1984) (Table 1), which are ca. 25% less than for conventional (aerial or ground sprayer) applications, are valid.

Table 1. Costs of conventional and chemigation application of chemicals.[a]

	Costs		
Type of chemical	Conventional ($/ha)	Chemigation ($/ha)	Water applied (mm) via chemigation
Fertilizer	7.54	6.17	12.7
Herbicide	19.18	4.93	10.2
Insecticide	7.54	1.92	4.1
Fungicide	7.54	1.92	4.1
Nematocide	19.18	6.17	12.7

[a] All applications made by injecting the insecticide formulations into the irrigation system using check valves, etc., as legally required for irrigation systems. (Threadgill 1984)

All applications discussed here were made by injecting the insecticide formulations into the irrigation system using check valves, etc., as legally required for irrigation systems (Threadgill 1984). The studies were conducted in South Georgia using either small research pivots, set systems, farmer-owned systems, or a center-pivot simulator. The data were analyzed as a randomized complete block design, and means were separated by the Waller-Duncan procedure (Waller and Duncan 1969).

The first trial reported here included methomyl, a water-soluble compound, which is the standard for controlling the fall armyworm (FAW), Spodoptera frugiperda, (J. E. Smith) (Table 2) (Young et al. 1981). The methomyl was injected into a set irrigation system using various water rates. Control was determined by counting the number of plants with FAW damage prior to treatment and at 48 hrs post-treatment on new growth. It is obvious that some insect control was achieved with all rates of water, but the control was not economical (less than 5% damaged plants under heavy insect pressure) at $>$ 468 L/ha. Thus, better FAW control was necessary for chemigation to be a viable application method. Therefore, a series of studies was conducted to determine if a water-insoluble oil formulation gives good control. From these studies, it was determined that a marked improvement in insect control occurred when the insecticides are formulated in oil. It also was determined that chlorpyrifos is a more effective insecticide for controlling the FAW than methomyl and more suitable for chemigation because it is practically insoluble in water but very soluble in oil. Therefore, we compared three

Table 2. Fall armyworm infestation before (Aug. 17) and after (Aug. 23) insecticide applications using a set irrigation system with impact sprinklers.

	% Infested corn plants			
	3369A		X304C	
Volume of water (L/ha)	Before insecticide	After insecticide	Before insecticide	After insecticide
468	93 a	8 a	93 a	4 a
15875	100 a	54 d	90 a	25 c
31750	92 a	46 c	84 a	13 b
63500	92 a	41 bc	93 a	34 d
127000	99 a	54 d	92 a	38 de

(Young et al. 1981)

formulations (Table 3) applied to pie-shaped sections of an 81-ha pivot: Lorsban 4-E plus water; Lorsban 4-E plus a nonemulsified petroleum oil (to eliminate the effects of the emulsifier in the 4-E formulation) and the technical chlorpyrifos-6 plus nonemulsified oil for control of FAW infesting field corn. The field corn was a tropical hybrid (Pioneer X304C) that had been planted in July as a late-forage crop. The field had been treated three times previously with methomyl using conventional equipment (both a ground sprayer using 233 L/ha and by air using 47 L/ha) without obtaining control of the FAW infestation. The crop had been abandoned by the farmer because the corn was still heavily damaged and infested with large larvae (multiple 5th instars per plant). Mean % control was determined by each of four workers, who checked to see if the larvae were dead or alive. The oil formulation without an emulsifier (tech + oil) gave significantly better FAW control than either the EC + Water or EC + oil treatments. Larvae in the

Table 3. Control of fall armyworm in X304C field corn with three solutions of chlorpyrifos (0.56 Kg/ha) applied in 7.6 mm irrigation water with an 81-ha center-pivot irrigation system having impact sprinklers. Corn at pretassel stage.

Treatment	Mean % mortality (48 hrs)
Chlorpyrifos EC + water	50 b
Chlorpyrifos EC + 7N oil (1.17 L/ha)	63 b
Chlorpyrifos Tech + 7N oil (1.52 L/ha)	94 a
Check	0 c

Water temperature 20-21°C (68-70°F).
(Young 1980)

tech + oil treated area were very difficult to locate and categorize following treatment. Rapid plant growth and larval movement during intoxication exposed the larvae to the effects of wind and rain, which blew or washed them to the ground where they were extremely difficult to detect. Although no significant difference could be determined for control in the EC + oil and the EC + water, again the larvae were easily found in the EC + water treatment but more difficult to locate in the EC + oil plots, indicating that the treatment was better than the mean % mortality indicated. Unfortunately, we did not record mean % plants damaged, which would have helped to elucidate this point.

To continue the study on the relative efficiency of the Lorsban 4-E + oil and the Lorsban Tech-6 + oil for controlling the FAW infesting Pioneer X304C field corn, the two formulations were applied by farmers to late-planted corn under two center pivots ca. 32 km apart. The first applications were made 10 and 15 days post-planting and the remainder were made either at weekly intervals or more frequently when 30% or more of the plants had visible damage to the developing whorl. Results of this study again indicated that the formulation without an emulsifier was superior in that it required only five applications of the Lorsban Tech-6 + oil to achieve the same yields as obtained with 12 applications of the Lorsban 4-E (Table 4).

Table 4. Effects of two formulations of chlorpyrifos (0.56 kg/ha) on the number of applications required to control fall armyworm infesting the vegetative stage of Pioneer X304C field corn.

Formulation	Water/application/(mm)[b]	Oil rate (L/ha)	No. applications	Yield/ha (tons)
Lorsban 4E/oil[a]	5.1	1.2	12	20
Lorsban Tech/oil[a]	6.3	1.5	5	17

[a] Peanut oil, once refined.
[b] Impact sprinklers, water temperature 20-21°C (68-70°F).
(Young 1982)

In an effort to establish a standard treatment formulation for insectigation of corn, trials were conducted with a combination of chlorpyrifos and permethrin at both light (spring) and heavy (summer) insect pressures (Table 5) for simultaneous control of the FAW and corn earworm (CEW). The applications were made to quadrants of a 6.5-ha pivot in 2.54 mm of irrigation water. Results indicated that the insect pressure was light in the spring crop (only 45.3% infested ears in the check), but extremely heavy in the summer (99.8% infested ears). Insect control however, was excellent in both crops, indicating that the treatment could serve as a standard.

These studies confirmed that chemigation of insecticides formulated in oil was an effective method for controlling CEW and FAW in corn. Therefore, a

Table 5. Control of the corn earworm and fall armyworm in Silver Queen sweet corn with chlorpyrifos (0.56 kg + permethrin 0.056 kg + crop oils [a]) applied in 2.54 mm irrigation water with impact sprinklers.

	No. applications	No. ears harvested	% Ears infested
Spring crop	15	1031	0.4
Check	-	360	45.3
Summer crop	26	1782	0.1
Check	-	933	99.8

[a] Suntec 6N crop oil, water temperature 20-21°C (68-70°F).

series of formulations and experiments was used to determine if an oil additive would be effective with an encapsulated formulation of methyl parathion (Penncap M plus Rohm and Haas 363-M emulsifier), and technical methyl parathion plus chlorpyrifos. These were compared to chlorpyrifos plus fenvalerate and technical cypermethrin for controlling the CEW and FAW infesting sweet corn during the spring. Recommended rates of the formulations were applied to quadrants (0.2 ha) of an 0.84-ha center pivot. Results (Table 6) again show the benefit of an oil formulation: 5.4% damaged ears in the Penncap M + oil vs. 15.6% for Penncap M + water. Technical methyl parathion

Table 6. Control of the corn earworm and fall armyworm in spring-planted Silver Queen sweet corn with chlorpyrifos (0.56 kg/ha) plus various other insecticides applied in 3.8 mm water with impact sprinklers.

Formulation	Insecticide/oil[a] Rate kg/ha	Insecticide/oil[a] Rate L/ha	No. applications	% Damaged ears	Mean damage index[b]
Penncap M/water	0.56	1	14	16	1.8 b
Penncap M/oil	0.56	1	14	5	1.3 b
Fenvalerate/ chlorpyrifos/oil	0.056 0.28	1	14	4	1.2 b
Methyl parathion/ chlorpyrifos/oil	0.56 0.28	1	12	8	1.6 b
Fenvalerate/ chlorpyrifos/oil	0.056	1	12	5	1.6 b
Cypermethrin/oil	0.056	1	12	5	1.7 b
Check	-	-	-	45	3.7 a

[a] Peanut oil, once refined, water temperature 20-21°C (68-70°F).
[b] Based on cm scale (Widstrom 1967)
(Young 1984)

plus chlorpyrifos plus oil did not control CEW any better than the Penncap M + oil. All oil formulations, including the cypermethrin, controlled insects as well as the chlorpyrifos plus fenvalerate standard.

Following the excellent results with corn, a study was initiated to determine if chemigation could control insects on cotton (Table 7). Since previous studies (Herzog 1984) had indicated that cypermethrin was an excellent

Table 7. Control of insects in cotton (grown under an 0.8-ha center-pivot irrigation system using impact sprinklers) with insecticides applied in 7.6 mm of irrigation water (14 applications).

Treatment[a]	Rate (kg/ha)	Mean % damaged squares: Boll weevil	Mean % damaged squares: Heliothis spp. larvae	Seed cotton yield (kg/ha)
Cypermethrin (Tech)	0.067	33 a	0.1 a	3393
Cypermethrin (Tech)	0.028	35 a	0.3 a	3702
Cypermethrin/ Penncap M	0.028 0.056	18 b	0.9 a	3856
Cypermethrin/ methyl parathion (Tech)	0.028 0.56	14 b	1.0 a	3393

[a] Diluted in once-refined soybean oil, water temperature 20-21°C (68-70°F).

control agent of the Heliothis complex, the study was conducted with technical cypermethrin and methyl parathion for the control of Heliothis spp. and the cotton boll weevil, Anthonomus grandis on cotton. Untreated plots were not included in the study because of the limited plot area available, the 50-90% decline in yield in untreated plots, and the large number of insects invading the treated plots (Herzog 1984). There was a significant increase in the percent of squares (flower buds) damaged by the boll weevil when only the cypermethrin was used without methyl parathion or Penncap M, indicating that cypermethrin did not control the weevil. However, there was no discernible dose effect with either the cypermethrin or the two formulations of methyl parathion for weevil control. Heliothis larval control was variable between treatments but not enough to be significant. Cotton yields were not significantly different among the treatments; all gave excellent yields. Results again indicated that chemigation of oil formulations is a viable concept for the control of insects infesting cotton.

The effects of soybean and peanut oils on efficacy of chlorpyrifos plus either Penncap M, permethrin, fenvalerate, or cypermethrin were determined (Table 8). Both spring- and summer-planted Silver Queen sweet corn was treated. The treatments were applied to either 0.56-ha quadrants of a one-tower, 0.81-ha pivot in 7.62 mm of irrigation water or to 1.6 ha of a 6.5-ha pivot in 2.54 mm water. No significant differences in insect control were obtained between the oils or among the treatments, indicating that a virtually damage-free crop was obtained.

Table 8. Control of the corn earworm and fall armyworm in Silver Queen sweet corn with technical chlorpyrifos (0.28 kg/ha) plus various other technical insecticides dissolved in either soybean or peanut oil and applied at 1.5 L/ha[a/] with impact sprinklers.

Treatment	Rate (kg/ha)	Season	No. appli-cations	Mean damage index[b/]	mean % worm-free ears
Soybean oil diluent					
Permethrin	0.056	Spring	13	1.2	97
Fenvalerate	0.056	Summer	10	1.3	94
Methyl parathion	0.056	Spring	13	1.2	98
Peanut oil diluent					
Permethrin	0.056	Spring	16	1.0	97
Permethrin	0.056	Summer	18[c/]	1.0	100
Fenvalerate	0.056	Spring	11	1.3	96
Fenvalerate	0.056	Summer	12	1.0	100
Methyl parathion	0.56	Spring	12	1.2	93
Methyl parathion	0.56	Summer	13	1.5	94
Cypermethrin	0.056	Spring	13	1.5	96

a/ Diluted to 1.5 L/ha and applied in 2.54 or 3.8 mm of irrigation water; water temperature 20-21°C (68-70°F).
b/ Based on cm scale (Widstrom 1967)
c/ 2.54 mm of irrigation water and 1.6-ha plots.
(Young 1984)

An additional study was conducted to determine the effect of various types of oil on the performance of chlorpyrifos for control of FAW infesting seedling field corn (Table 9). The treatments were applied to ca. 10-day-old seedling Pioneer X304C field corn using a center-pivot simulator (Sumner et al. 1987) and 2.54 mm of irrigation water. Pretreatment surveys were made the day of treatment, and post-treatment surveys were made 48 hrs after the applications. Significant differences in FAW were found for various oil formulations within a given trial; however, the results were not consistent across trials, indicating a variation in insect population pressure as verified in the check treatment that received only water. This study again suggested that a wide variety of oils can be used for chemigation of chlorpyrifos, using the solubility of the chemical and oil costs as the major factors for selection of an oil.

The final formulation we considered in these trials was an oil additive to the Larvin 500 flowable formulation of thiodicarb. Suntec 6N was added to the flowable formulation in a 1:1 ratio using Rohm and Haas 363M emulsifier

Table 9. Reduction in % damaged plants at 48 hrs following the control of fall armyworm larvae infesting seedling corn with technical chlorpyrifos (0.56 kg/ha) in various oil solvents, applied in 2.54 mm irrigation water with a center-pivot simulator.

Treatment	Mean % damaged Plants[a]	
	Pretreatment	48 hr post treatment
Gulfsol 20	97	20 a
Orchard spray 70	96	18 a
Peanut oil	95	32 a
Soybean oil	86	25 a
Suntec 6N	96	31 a
Gulfsol T	85	26 a
Kerosene	97	22 a
Check	98	67 b

a/ Means are over 2 trials of 4 replications and within columns followed by the same letter are not significantly different.

(0.4%) to make a uniform suspension (Table 10). This was compared to adding Pinolene, a spreader-sticker, at a 1:1 ratio to the insecticide volume.

Table 10. Control of corn earworm and fall armyworm larvae infesting the ear of Silver Queen sweet corn with thiodicarb (Larvin-500 4F) plus either pinolene or oil applied in 2.54 mm irrigation water with a center-pivot irrigation system having impact sprinklers.

Treatment/ crop season	Insecticide/oil Rate		No. applications	% Damaged ears	Mean damage index[a]
	kg/ha	L/ha			
Thiodicarb/Pinolene[b] (Spring)	0.84	0.5	12	71 a	3.47 a
Check	-	-	-	45 b	3.04 a
Thiodicarb/ oil[c]/363-M[d] (Summer)	0.84	0.5	24	1.2 c	1.03 b

a/ Based on cm scale. (Widstrom 1967)
b/ NuFilm-17, Miller Chemical and Fertilizer Corp., water temperature 20-21°C (68-70°F)
c/ Suntec 6N, Sun Petroleum Products Co.
d/ Oil emulsifier, Rohm & Haas Co.

The addition of the Pinolene to the formulation increased the % of damaged ears over that of the check. However, adding the oil to the formulation controlled insects as well as expected with the standard used in previous studies. This again indicated the need for a formulation that has no solubility in water but for one that has an affinity for insects and plants.

In conclusion, we were able to show that the presence of an emulsifier in the formulation injected into the pivot reduced the insect control, even with an oil additive. Although we did not present the data, Table 11 lists

Table 11. Crops treated and insects controlled effectively by insectigation.

Crops	Insects Controlled
Corn - Field & Sweet	Corn earworm, fall armyworm, stink bugs, spider mites, aphids
Sorghum	Corn earworm, fall armyworm, and stink bugs
Soybeans	Corn earworm, soybean looper, velvetbean caterpillar & stink bugs
Cucumbers & squash	Spotted cucumber beetle and pickleworm
Cauliflower, cabbage, collards & broccoli	Cabbage looper and imported cabbage worm
Southern peas	Pea weevil and lesser cornstalk borer
Turnips	Diamondback moth and aphids
Tomatoes	Tomato fruitworm, corn earworm, and Colored potato beetle
Peanuts	Thrips, leafhoppers, corn earworm, and fall armyworm
Spinach	Vegetable weevil, leafminer, and tarnished plant bug
Lima beans	Stink bugs and corn earworm
Snapbeans	Thrips
Tobacco	Caterpillars and aphids
Cotton	Boll weevil, caterpillar group

crops treated and the insects we have controlled with the oil formulations. Table 12 lists the insecticides we have used both successfully and unsuccessfully. The successful compounds were used either as an oil additive or as a technical material in an oil formulation. Unfortunately, only carbaryl and chlorpyrifos are presently registered for insect control via chemigation by the Environmental Protection Agency.

Table 12. Insecticides that have been used successfully and unsuccessfully for insectigation.

Compounds and formulations used successfully	
Lorsban® (chlorpyrifos)-Tech, 4E	Disyston® (disulfoton)-8E
Gardona® (stirofos)-4F	Thiodan® (endosulfan)-2E
Sevin® (carbaryl)-80S, 4 oil	Toxaphene, Tech, 8EC
Boldstar® (sulprofos), 6EC	Furadan® (carbofuran), 4F
Larvin® (thiodicarb), 4F, oil	Methyl parathion, Tech, 4EC
Pydrin® (fenvalerate), Tech, 2.4EC	Mesurol® (methiocarb), 75WP
Ammo®, Cymbush® (cypermethrin), Tech 2.0EC, 4-oil, 3EC	Malathion, Tech, 4E
	Diazinon, 4E
Orthene® (acephate), 75S	
Comite® (propargite), 6EC	
Kelthane® (dicofol), 1.6EC	
Ambush®, Pounce®, (permethrin)-Tech, 3.2EC, 2EC	
Compounds that were not successful	
Lannate®, Nudrin® (methomyl), 1.8WM	
Cygon® (dimethoate), 4WM	
Azodrin® (monocrotophos), 5WM	

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VEGETABLES: CONTROL OF THE COWPEA CURCULIO, TOMATO FRUITWORM AND CABBAGE LOOPER ON SOUTHERN PEA, TOMATO AND COLLARDS, RESPECTIVELY, BY CHEMIGATION OF INSECTICIDES (INSECTIGATION)

by

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Research on chemigation of vegetable crops in Georgia has shown that insect pests of the major vegetable crops can be controlled with chemigated insecticides (Chalfant and Young 1982, 1984). Some technical improvements in application are reflected in the following tests. These include check plots under the center-pivots, direct comparisons between insecticides applied by chemigation and ground sprayers, and improvements in the chemigation simulator.

METHODS AND MATERIALS

Two trials with southern peas and one with tomato under a 0.8 ha center-pivot were conducted on Hays Research Farm near Camilla, GA. Three quadrants received chemigated insecticides and the fourth received irrigation water only and served as the check. Insecticides were dissolved in a 1:1 ratio in non-emulsified vegetable or mineral oils, and delivered at a rate of 4942 ml/ha formulated product. The formulations were injected into the irrigation line near the pivot point using an FR121A-73M Roy (Milton Roy Co.) pump at a pressure of 2 kg/cm^2. Insecticidal performance was evaluated by recording insect damage on 50 pods of fruits harvested from four sampling sites per quadrant. Insect damage consisted of stings from cowpea curculio, *Chalcodermes aeneus* Boheman, on the peas, and holes in the tomatoes from fruitworm, *Heliothis spp*. Insecticides on southern peas were applied, beginning at anthesis, at *ca*. four-day intervals. On the tomato treatment was made beginning at fruit formation. Application dates are shown in Tables 1 and 2.

Additional tests (Sumner et al. 1987) were conducted with southern peas and collards using a chemigation simulator. The simulator was a self-propelled, 9m-wide irrigation truss raised 2m over the ground and equipped with Spraying Systems® sprinklers (8050) spaced 100 cm apart. The boom was divided so that two 4.5m-wide linear plots could be chemigated simultaneously using two independent pumps to inject the insecticides, formulated as above, into the irrigation trusses. Water was supplied through a flexible hose connected to the irrigation line. These treatments were compared in nearby plots with insecticides applied with a tractor-mounted 2-row sprayer equipped with three Spraying Systems® T-18 hollow-cone nozzles per row and delivering 189 liters water per hectare at a pressure of 515 gm/cm^2. Plots under the simulator were 5 rows, 5m wide and 5m long. Those under the tractor sprayer were 2 rows, 2m wide and 5m long. Experimental design was a randomized complete block with four replications. Peas were sampled as described above. Collards were examined at harvest for defoliation caused by cabbage loopers,

Table 1. Cowpea curculio oviposition stings on southern peas grown under a 0.8 ha center-pivot and treated with chemigated insecticides.

Insecticide	kg/ha	No. stings/300 gm samples[b] 1982[c]	1983[d]
Penncap-M 2-encap. in water	1.1	27b	--[a]
Penncap-M 2-encap. in oil	1.1	17a	14a
Penncap-M 2-encap. in oil	0.6	--[a]	32b
Penncap-M 2-encap. + permethrin 2E in oil	0.6 + 0.06	41c	--[a]
Fenvalerate 0.4 oil	0.11	--[a]	6a
Untreated check		97d	52c

a/ Not tested.
b/ Means with letters in common are not significantly different.
c/ Planted June 30; treated Aug. 6,9,13,17; harvested Aug. 23.
d/ Planted July 6; treated July 23,29, Aug. 20,22,29; harvested Sep. 6.

Table 2. Tomato fruitworm[a] infestation on tomatoes grown under a 0.8 ha center-pivot and treated with chemigated insecticides.

Insecticide, kg/ha	kg/ha	Percent infested fruit[b],[c]
Penncap-M 2-encap. in oil	1.1	13.7c
Permethrin 0.4 oil	0.11	3.7b
Penncap-M 2-encap. + permethrin 0.4 oil	0.5 + 0.06	2.7a
Untreated check		38.7d

a/ *Heliothis spp.*
b/ Means with letters in common are not significantly different.
c/ Treated May 29, June 5,21,28; harvested June 27, July 2,9.

Trichoplusia ni Hubner, using a 0-5 intensity scale. On southern peas insecticides were scheduled as described above. On collards insecticides were applied beginning with infestation. Application dates are shown in Table 3.

Table 3. Cowpea curculio oviposition stings on southern peas grown in replicated plots and treated with insecticides applied with a chemigation simulator and a conventional sprayer.[a]

		Simulator		Sprayer	
Insecticide	kg/ha	Formulation	Stings[b]	Formulation	Stings[b]
Cypermethrin	0.06	tech. in oil	18c	2.5E	8b
Permethrin	0.1	0.4 oil	10bc	2E	17b
Cyfluthrin	0.06	2E	6b	2E	5a
Fenvalereate	0.1	4 oil	10bc	2.4E	10a
Cyhalothrin	0.02	1 oil	1a	1E	4a
Untreated check			40d		40c

a/ Treated Sep. 18,24,28.
b/ Means with letters in common are not significantly different.

RESULTS

Tests on southern peas and tomatoes under the 0.6 ha center-pivot at Camilla are shown in Tables 1 and 2, respectively. In 1982, 1.1 kg/ha Penncap-M® formulated in once-refined soybean oil gave best control of cowpea curculio stings and was significantly better than the same material formulated in water or combined at a 0.6 kg/ha rate with 0.06 kg/ha of permethrin. In 1983, only oil formulations were used. Penncap-M, 1.1 kg/ha in oil, gave essentially the same level of control as in 1982 and was equal to 0.11 kg/ha of fenvalerate. On tomatoes, against fruitworms, a combination of 0.6 kg/ha Penncap-M and 0.06 kg/ha permethrin was significantly better than either component used singly at twice their respective rates.

Tests on southern peas comparing the center-pivot simulator and conventional sprayer are shown in Table 3. With both methods peas treated with cyfluthrin and cyhalothrin had fewest cowpea curculio stings giving > 90% reduction. The 2EC formulation of cypermethrin was effective when sprayed while the oil formulation of technical was not when chemigated.

Comparison between the chemigation simulator and ground sprayer against cabbage loopers on collards is shown in Table 4. Because infestation was lower in the sprayed plots, results are expressed as % control [(untreated-treated/untreated)*100]. Although good reduction of feeding damage was obtained with both the simulator and sprayer, there were some differences between specific insecticides. Permethrin and Dipel® (*Bacillus thuringiensis* Berliner) gave better control when applied by the sprayer than by the simulator. Cyhalothrin at 0.01 kg/ha appeared to be better when chemigated, although differences between application methods could not be analyzed because of the experimental design.

Table 4. Cabbage looper[a/] feeding damage[b/] on collards grown in replicated plots and treated[c/] with insecticides applied with a chemigation simulator and a conventional sprayer.

Insecticide, formula	kg/ha	Percent Control[d/] Simulator	Percent Control[d/] Sprayer
Cypermethrin 2.4E	0.06	78 def	75 bc
Permethrin 2E	0.1	63 c-f	98 c
Cyfluthrin 2E	0.03	80 ef	73 bc
Cyfluthrin 2E	0.06	96 f	92 bc
Cyhalothrin 1E	0.01	91 f	57 bc
Cyhalothrin 1E	0.02	90 f	92 bc
Dipel 4L	0.95 L[e/]	26 b	51 b
Dipel 4L	1.9 L	38 bc	65 bc

a/ Cabbage looper = *Trichoplusia ni* Hubner
b/ Score = 0-5 intensity scale; means with letters in common are not significantly different.
c/ Treated Oct. 22,26, Nov. 5,16.
d/ (Untreated score-treated score/untreated score)*100.
e/ .95 L = 16,000 BIU/acre.

DISCUSSION

On southern peas the tolerance for Cowpea Curculio damage established by processors within Georgia is 10 stings per 300 gm sample. Under the center-pivot at Camilla, application of fenvalerate gave sufficient control to meet this tolerance. Penncap-M 1.1 kg/ha in oil approached the tolerance. On tomato chemigation also produced essentially damage-free fruit. These data lend confidence to our previous conclusion (Chalfant and Young 1982, 1984) that chemigation is at least as effective as conventional sprayers for applying insecticides. Favorable comparisons between a center-pivot simulator and a tractor-mounted sprayer on collards and southern peas reinforce these conclusions, although the simulator lacks certain attributes of the center-pivot, such as lower height and short length of the truss.

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EXTENSION'S ROLE IN CHEMIGATION:
CHEMIGATION TRIALS FOR CONTROL OF POTATO PESTS IN WISCONSIN

by

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The state of Wisconsin grows approximately 26,000 ha of potatoes annually. The majority of this acreage is located in a four-county area referred to as the central sands area, which is characterized by a loamy sand soil with a shallow water table ranging from 1 to 7 m. Essentially all potatoes in the central sands region are grown under center-pivot irrigation systems that generally cover from 20 to 65 ha.

Insect control on potatoes has been typically achieved by the soil application of a systemic insecticide plus one or more applications of a foliar insecticide after the effectiveness of the systemic materials has decreased. However, the detection of pesticide residues in the ground water resulting from the soil application of insecticides to potatoes (Wyman et al. 1985) has resulted in an increase in the use of foliar insecticides on potatoes. The majority of these foliar insecticides, as well as fungicide applications, are made by aircraft, which allows the treatment of a large number of acres in a relatively short time. However, the problems of drift and overspray associated with aerial applications of pesticides has caused increased public concern about the aerial application method. In addition, scheduling of aerial applications can often be a problem, since over 50% of Wisconsin's potato acreage is scouted and many of these acres require insecticide applications on short notice.

This trend of increased foliar insecticide applications is expected to continue, and there is a need to investigate other methods of insecticide applications which will continue to provide effective pest control. Chalfant and Young (1982) have successfully demonstrated the application of insecticides through overhead sprinkler irrigation systems to control numerous insects on various vegetable crops. In addition, center-pivot systems have been used to apply both fungicides (McMaster and Douglas 1976) and herbicides (Callihan and McMaster 1976) to potatoes. Thus, studies were conducted from 1980 to 1983 to demonstrate the utilization of center-pivot irrigation systems as delivery mechanisms for insecticides to potatoes.

Two different application methods utilizing the center-pivot irrigation system were evaluated. Direct injection of materials into the irrigation water of the center-pivot system, and application through an underslung boom mounted with adjustable support carriers on the center-pivot irrigation system such that the boom was carried ca. 1 m above the plant canopy. The boom was equipped with floodjet nozzles, and materials were applied through the boom simultaneously with application of water through the overhead center-pivot system.

In 1980, the potato leafhopper, <u>Empoasca fabae</u> (Harris), was the predominate insect pest in these trials, and the application of acephate by the two

above-mentioned application methods provided insect control comparable to the conventional tractor-mounted boom application (Table 1). In 1981, the Colorado potato beetle, Leptinotarsa decemlineata (Say), became the predominate insect pest, and four materials applied via the underslung boom were

Table 1. Potato leafhopper control on potatoes treated with acephate (1.21 Kg AI/ha) by different application methods (Hancock, WI, 1980).

Application method	Mean no. leafhoppers per 25 sweeps[a] (Days post applications) 1	9
Tractor-mounted boom	85 a	5 a
Underslung boom	71 a	11 a
Center-pivot system	57 a	2 a
Untreated Control	113 b	90 b

[a] Numbers in the same column followed by the same letter are not significantly different by Duncan's new multiple range test (P=0.05).

evaluated for effectiveness. All materials provided excellent control when applied by the tractor-mounted boom (Table 2). However, the pyrethroid materials fenvalerate and permethrin were the only insecticides to provide effective insect control when applied through the underslung boom.

Table 2. Colorado potato beetle control on potatoes treated with insecticides by different application methods (Hancock, WI, 1981).

Application method	Insecticide	No. beetles per 10 sweeps[a] (Days post application) 1	6
Tractor-mounted boom	Permethrin	1 a	6 a
	Fenvalerate	1 a	1 a
	Acephate	6 a	13 a
	Methamidophos	1 a	8 a
Underslung boom	Permethrin	10 a	35 b
	Fenvalerate	2 a	10 a
	Acephate	28 b	45 b
	Methamidophos	21 b	35 b
Untreated Control	--	38 b	45 b

[a] Numbers in the same column followed by the same letter are not significantly different by Duncan's new multiple range test (P=0.05).

In 1982, three insecticides were evaluated for effectiveness when applied by direct injection into the center-pivot system. Similar to application via the underslung boom, only the pyrethroid fenvalerate provided significant

Colorado potato beetle control when applied through the center pivot system (Table 3). The decreased efficacy of acephate and methamidophos when applied utilizing the center-pivot irrigation system was probably due to its solubility in water, which did not allow it to adhere to leaf surfaces (Young 1980). The efficacy of carbaryl may have been improved had a non-emulsified oil been added to the material prior to injection (Young et al. 1981). Thus, the success of chemigation for insect control is highly dependent on the materials used.

Table 3. Colorado potato beetle control on potatoes treated with insecticides by different application methods (Hancock, WI, 1982).

Application method	Insecticide	No. beetles per 15 sweeps[a/] (Days post application) 1	6
Tractor-mounted boom	Fenvalerate	1 a	1 a
	Methamidophos	4 a	10 b
	Carbaryl	10 a	92 c
	Untreated control	249 c	268 d
Center-pivot system	Fenvalerate	3 a	2 a
	Methamidophos	137 b	141 cd
	Carbaryl	122 b	127 cd
	Untreated control	321 d	248 d

a/ Numbers in the same column followed by the same letter are not significantly different by Duncan's new multiple range test (P=0.05).

To compare the efficacy of chemigated fenvalerate with the efficacy of ground and aerial applications, studies were expanded in 1982 and 1983 to include chemigation of a 64.8 ha commercial field of potatoes in the central sands region. In 1982, two applications of fenvalerate were required for potato leafhopper control, and although all three methods provided excellent initial knock-down of leafhoppers, the tractor-mounted boom method showed the longest residual activity (Fig. 1). Center-pivot applications exhibited more residual activity than aerial; however, all three methods provided

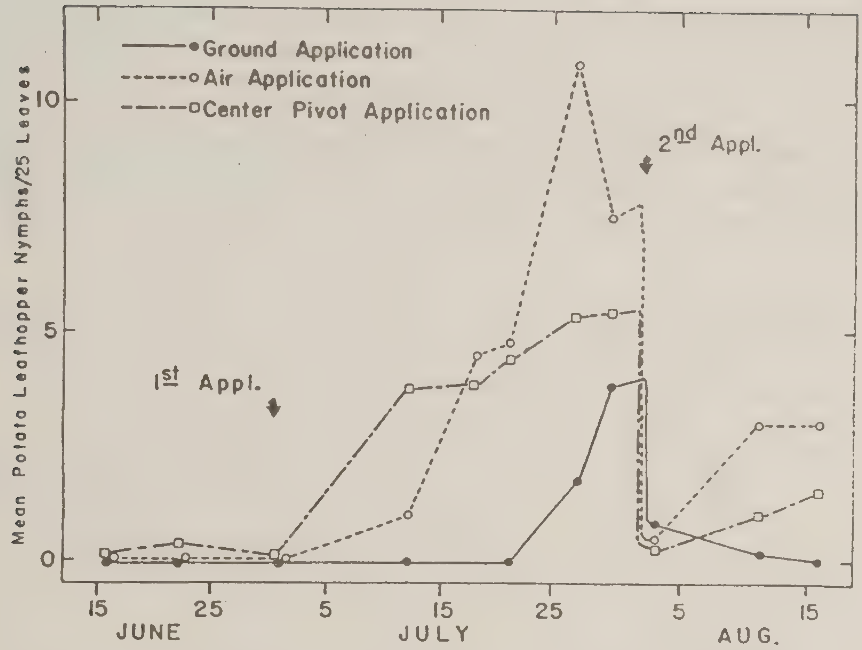

Figure 1. Potato leafhopper population trends on potatoes treated with fenvalerate by different application methods (Coloma, WI, 1982).

acceptable levels of insect control as indicated by yields (Table 4). No differences were detected among treatments, and yields were very similar to the yield of potatoes from aldicarb treated plots, which had extremely low numbers of insects throughout the season.

Table 4. Yields of Russet Burbank potatoes treated with fenvalerate by different application methods (Coloma, WI, 1982).

Application method	Yield (metric tons/ha)[a]
Tractor-mounted boom	40.4 a
Center-pivot system	40.8 a
Aerial	38.1 a
Aldicarb at hilling	40.2 a

[a] Numbers in the same column followed by the same letter are not significantly different by Duncan's new multiple range test (P=0.05).

In 1983, both the center-pivot and aerial applications of fenvalerate and permethrin provided excellent control of the potato leafhopper (Table 5). The high level of control was evident by the higher number of insects recorded in the aldicarb treated potatoes. In addition, high yields were obtained from all treatments, with a field average of 52.1 metric tons per ha. Although analysis of variance was not possible on yield data, yields from the aldicarb treated potatoes were slightly lower than the yields from all other treatments; further evidence that acceptable levels of insect control was provided with center-pivot and aerial applications of either insecticide.

Table 5. Potato leafhopper control and yields of potatoes treated with insecticides by two application methods, and with aldicarb at hilling (Coloma, WI, 1983).

Application method	Insecticide	Mean No. leafhoppers/15 sweeps[a/] (Days post application) Pre-trt.	1	8	(metric tons/ha)
Center-pivot	Fenvalerate	82 ab	2 a	4 a	52.2
	Permethrin	81 ab	1 a	1 a	54.1
Aerial	Fenvalerate	130 b	0 a	2 a	51.3
	Permethrin	105 b	1 a	3 a	51.9
--	Adlicarb	15 a	22 b	35 b	50.8

[a/] Numbers in the same column followed by the same letter are not significantly different by Duncan's new multiple range test (P=0.05).

The successful demonstration of applying insecticides to large acreages of potatoes via the center-pivot system has led many growers to rely on chemigation for both insect and disease control. The use of center-pivot irrigation systems for pesticide applications is expected to continue to grow over the next five years, and it is important that additional questions be answered. Specifically, do efficacy differences exist between low and high pressure center-pivot irrigation systems, and what is the drift potential of this type of application method?

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EXTENSION'S EXPERIENCE WITH INSECTIGATION IN COLORADO: EQUIPMENT, OIL ADDITIVE, AND CONTROL OF EUROPEAN CORNBORER AND WESTERN BEAN CUTWORM IN FIELD CORN

by

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There are about 5,000 center-pivot systems in Colorado, covering approximately 265,000 hectares. This represents one-fifth of the total irrigated area in Colorado, and a substantial portion of the intensively managed irrigated areas. The major irrigated crops include field corn, dry bean, sugar beet, sorghum, and small grains (winter wheat and spring barley) with a small acreage of sunflower and popcorn.

The application of fertilizers through center-pivots was started in the late 1950's (Fischbach 1971) and now is a common practice in Colorado, especially on sandy soils. Studies on weed control have been conducted with herbicides (Colorado Weed Control Test Plots) since 1972 by P. E. Heikes of Colorado State University (CSU). His work dealt primarily with pre-plant herbicides application on field corn. This practice has not been widely adopted, because of the inability to time the application, in that an irrigation prior to planting creates a time delay in planting. Another factor delaying the use of herbigation involves the sprinkler system. Most sprinklers set idle during the fall and winter months - thus there are many mechanical problems associated with the start-up of the system at the beginning of a cropping season.

Dr. M. Harrison, CSU Plant Pathologist, and others also have studied the application of fungicides through center-pivot systems. Generally, they have had a great deal of success in controlling early blight in potatoes and bacterial leaf blight on dry bean.

Insecticides were first successfully applied through center pivots in Colorado by the first author and Bill Hantsbarger in 1976. The first attempt at insect control involved Carbaryl (Sevin 80 Sprayable) for the control of western bean cutworm (WBC) Loxagrotis albicosta (Smith). We had many equipment problems, such as most of the injection pumps were piston type and required mechanical disassembly to adjust. Earlier pumps used in chemigation were designed to pump ten gallons or more of solution per hour and they were often inaccurate. Now we have Hydra-cone and Hydra-tube pumps that are capable of accurately pumping less than one gallon per hour. Another important aspect of pump design is that electrical motors can be obtained that meet National Electrical Code requirements when injecting some chemicals (explosion-proof wiring).

The next major obstacle to efficient insectigation involves hoses, fittings, filters, and seals. Many of these components that were marketed lacked resistance to the chemicals and their solvents. Generally speaking, teflon, nylon, and viton are the most resistant hose materials to insecticide formulations presently available. Fittings have posed a special problem, in that

under pressure and attack by the insecticide solution the "hose clamp" would "pop-off" contaminate the applicator, equipment, and soil and waste the chemical. Also, many fittings initially available reduced the flow of chemicals which required a larger hose and volume of chemical to obtain the required rate, again increasing the hazards of chemigation. Now there are male-female threaded couplings made of stainless steel and nylon with viton or nylon "o" rings that can be utilized for all connections without reducing flow through the hose.

Another safety device for metering or calibration is an "in-line" bleed valve placed in front of the check valve of the injection port. This valve allows the release of air pockets, etc., eliminating "air locking" in pumps.

The in-line check valve still poses a problem. The check valve we used became corroded and non-functional. If the injection pump stops, this may allow water to back through the injection line and pump (depending on the pump), causing overflow of the insecticide nurse tank and contamination of the area. It is suggested that a positive electric solenoid valve be used to eliminate this problem but a durable one is not presently available.

Many chemical or pesticide nurse tanks (insecticide reservoir), having a specific design characteristic, are now available for grower use. For insectigation, the tanks should be designed to facilitate easy filling and cleaning. There should be a closed container system with an air-vented lid to prevent foreign particle contamination of systems. The bottom of the tank should be cone-shaped and totally drainable. Also, the entire container needs to be as resistant to chemical and impact as possible.

Another important aspect of an insectigation system involves having "on-off" electrical switches for the injection pump and agitator. The switch allows operation of the injection pump without turning the well on and off.

The chemigation industry needs a private or University testing facility to establish acceptable chemigation equipment standards. Approved standards could then be incorporated into state and federal laws that are being made to regulate chemigation.

Presently, Colorado plans to test anti-back siphon valves for their reliability and use in chemigation. Also, Colorado plans laws that will require annual equipment inspection prior to usage.

INSECT CONTROL

Since CSU's first insectigation trial in 1976, fourteen formulations of seven insecticides have been tested on field corn (Unpublished data). Many of these formulations have given satisfactory control of first and second generation European corn borer (ECB) *Ostrinia nubilalis* (Hubner), western corn rootworm beetles, *Diabrotica virgifera* (LeConte), and western bean cutworm already mentioned.

European corn borer

First generation control

European corn borer has been an economic pest of corn in Colorado since 1981. Approximately 120,000 hectares of corn, grown in Northeast Colorado under center-pivot sprinklers, are potential hectarage for control of the ECB through insectigation. The first generation moth flight and ovipositon period are confined to a short time period. Thus, all ECB larvae mature within a small time difference. CSU recommends control when the foliage shows the presence of "shot hole" symptoms and the infestation level is 35% of the plants with live larvae. Insecticide application is recommended when a high percentage of the eggs have hatched but prior to tassel emergence. At this time the larvae have not formed cavities, are still mobile within the confines of the whorl of the plant and are most exposed to the chemical.

After compiling data from several tests with a nonemulsified oil added to the emulsified concentrate formulation, the formulation with the added oil appeared to give better insect control than the emulsified concentrate with water only added. Therefore, studies were conducted to compare the effects of an oil additive on control of first generation larvae infesting whorl stage field corn. Larval control with chlorpyrifos (1.15 kg/ha) and permethrin (0.17 kg/ha) plus either 2341 ml of oil or water per hectare, produced 79% vs 79% and 88% vs 88% control, respectively, with and without the oil (Table 1). However, with fenvalerate (0.17 kg/ha), a significant difference (ANOV-P.05) in % control was obtained, 73% with oil vs 54% without the oil. However, at the rates used and the timing of the single application, the addition of oil to EC formulations does not significantly increase the efficacy of the treatments for controlling first generation ECB.

Table 1. Effects of non-emulsifiable oil on chemigated insecticides for control of the European corn borer.

Insecticide	Formulation	Kg A.I. /ha	Year	% Larval control w/oil	% Larval control wo/oil	Oil Type*
First generation						
Chlorpyrifos	4.0 EC	1.15	1984	79	79	P
Fenvalerate	2.4 EC	0.17	1983	73	54	P
Permethrin	3.2 EC	0.17	1984	88	88	P
Second generation						
Chlorpyrifos	4.0	1.15	1983	79	55	P
Chlorpyrifos	4.0	1.15	1984	73	20	P
Fenvalerate	2.4	0.17	1983	84	53	C
Flucythrinate	2.5	0.09	1984	88	69	P
Permethrin	3.2	0.17	1982	58	45	C
Permethrin	3.2	0.17	1981		84	?

* P = Petroleum derived non-emulsified oil
C = Cottonseed oil-once refined

Second generation ECB larval control

Second generation ECB is difficult to control on corn. The economics of ECB control with insecticides depend largely on the stage of growth when infestation takes place. Physiological and mechanical injury to corn occurs if infestation is during the pollination period. When the infestation occurs late, loss in yield is due to the inability to mechanical harvest dropped ears, lodged plants etc. With timely harvest these losses can be minimized. Moth flights and oviposition can occur over 5 to 35 and 5 to 30 days, respectively. With this wide period of activity, two insecticide applications may be necessary for adequate control of ECB. The first application needs to be made before larvae enter the ear. Comparisons of control of second generation ECB over years (1982, 1983 and 1984) with the above chemicals and flucythrinate with and without an oil additive (Table 2), produced a significant (ANOV-P.05) increase in control with the oil additive. The percent improvement in control, in favor of the oil additive, varied from 24% (1983) to 53% (1984) for chlorpyrifos, 31% (1983) for fenvalerate, 19% (1984) for flucythrinate and 13% (1982) for permethrin.

Table 2. A comparison of larval control with aerially applied and insectigated insecticides of second general European corn borer on Colorado field corn.

Insecticide	Formulation	Kg/A.I./ha	Year	% Larval Control Aerial	Insectigated
Fenvalerate	2.4E	0.17	1983	70	72
Permethrin	3.2E	0.17	1980	77	83
Permethrin*	3.2E	0.17	1980	84	91
Permethrin	3.2E	0.17	1981	72	75

* Two applications, 14-day interval.

Aerial vs Chemigated Control

During discussions of insectigation at grower meetings, the question is often asked "Is insect control different when aerial vs insectigation applications with the same insecticide and rate is applied in the same field?" We thus compared three emulsifiable concentrate formulated insecticides in 1980, 1981 and 1983 for control of the second generation larvae. Water was added to the formulations to bring each up to a constant volume and make metering easier. Numerically, all of the insectigated treatments controlled second generation larvae (70% or greater, Table 2) with the same chemical applied either aerially or insectigated; however, the differences were not significant (ANOV P.05). A second application of permethrin improved the control, 84 and 91% respectively, with both methods of application again with the insectigated treatment numerically but not significantly better.

Western Bean Cutworm

The WBC, another insect pest of corn in northeast Colorado, is of economic importance on approximately 81,000 hectares of corn. The moth emerges in early July and flights last for 18 to 20 days. The eggs are laid on the leaf surface of the upper one-third of the plant. Time from egg deposit to larval emergence is approximately seven days. Larvae first move to the leaf axils, then up the plant where they feed in the whorl area until the tassel emerges. With ear formation, larvae move to the silks and eventually into the kernels. Control of larval once they enter the ear is difficult. CSU recommends insecticide control of WBC when 8% or more of the plants have egg masses and 95% of the plants have tasseled, but before larvae enter the ears. Chlorpyrifos (1.15 kg/ha) controlled 100% of the WBC (Table 3) with and 95% w/o the oil additive but the differences were not statistically significant (ANOV P.05). Control of the WBC was identical (100%) when permethrin and fenvalerate (0.06 kg/ha) were used with and without the oil additive. Results show that the WBC can be controlled with insectigated treatments when recommended rates are applied.

Table 3. Effects of non-emulsifiable plant-derived oil on chemigated insecticides for control of western bean cutworm.

Insecticide	Formulation	Kg A.I. /ha	Year	% Larval control w/oil	% Larval control wo/oil	Oil Type*
Chlorpyrifos	4.0 EC	1.15	1983	100	97	S
Permethrin	3.2 EC	0.06	1982	100	100	C
Fenvalerate	2.4 EC	0.06	1982		100	?

* S = Soybean oil - once refined
C = Cottonseed oil-once refined

DISCUSSION

First generation ECB and WBC can be controlled by either insectigation or aerial applications of insecticides. Applications need to be made when a high percentage of the eggs have hatched but before larvae enter the plant so that maximum contact with insecticide is obtained. No significant differences in larval control were shown when recommended rates of insecticides were applied by center pivots in either water or in a non-emulsified oil. The exception to this was that fenvalerate plus oil gave a significant increase in control of first generation ECB larvae.

Comparisons of aerial vs insectigation applications for control of the second generation ECB larvae produced a numerical advantage for the insectigation treatments. Since our plots were very large, side by side treatments with replications, they are only indicative of control that may be obtained with a single application of insecticide through a center pivot on a light infestation of ECB.

Second generation ECB can be controlled with a single treatment applied either by insectigation or aerial, if timed before larval "escape" into the ear. Also, if reinfestation by ECB larvae continues for up to 30 days, a second treatment gives improved plant protection. Addition of a non-emulsified oil improved the control of second generation ECB larvae because it gave better canopy penetration with the increase in water carrier, more desirable insecticide distribution and greater retention of the insecticide on the plant, and extended insecticide residue activity (Young 1982). All the treatments were applied with 12.7 mm/ha or less of water. If the total volume of water had been increased, efficacy of some of the insecticides (without oil) may have been decreased (Raun 1981).

Entomologists at CSU will continue to recommend the use of a non-emulsified oil with the emulsified concentrated insecticide formulations for first and second generation ECB and WBC control through insectigation. There are many variables that may affect the control of an insect with insectigation; such as, application timing, retention of the insecticide by the plant, water quality, total water volume, etc. Therefore, since our studies with an oil additive to the emulsified concentrate formulation always gave the superior or numerically greater insect control, we conclude that farmers should use an oil additive for all insectigation applications. Also, the chlorpyrifos label requires the addition of a non-emulsified oil to be in compliance for insect control with chemigation.

This summary of insectigation and recommendations in Colorado leaves many unanswered questions. What effect does droplet size created by different sprinkler nozzle packages have on insecticide-oil formulations, and their retention, distribution, and insecticidal activity? For example, what role does water temperature have on the performance of different oils? Could more oil and less insecticides be an effective treatment? In spite of these and other unanswered questions, we conclude that insectigation is a viable means of applying insecticides for the control of the ECB and WBC infesting field corn in Colorado.

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CONSULTANT'S ROLE IN CHEMIGATION:
INSECTIGATION THROUGH THE GROWERS' VARIABLE EQUIPMENT

by

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ABSTRACT

Since 1975, I have been working with growers testing and using insecticides through center-pivot irrigation systems. These are systems which farmers originally had installed to irrigate their crops in the western corn belt and High Plains where annual rainfall averages from 14 to 20 inches per year. Rainfall in these areas usually comes during the spring and early summer, thus making it imperative that the farmers add water during much of the summer.

During the late 70's the electric-drive systems were replacing the old water-drive systems. These electric-drive systems made it possible to control the volume of water flowing through the center-pivot more easily than had been possible by using the water-drive systems. Electric-drive systems could put on as little as 0.25 acre-inch of water, or as much as 2 acre-inches, during the transit of a revolution. Since then, even faster electric systems are now available that can apply as little as 0.05-0.10 acre-inch at a revolution.

In early trials it was necessary to apply insecticides through sprinkler systems that would apply low volumes of water (Boeckman, 1978; Raun, 1979). Since Young (1981) has shown that oil solutions of insecticides can be applied through center-pivot systems, we have been using all types of systems, speeds and volumes of water up to 1.5 acre-inches per application for chemigation.

The changes in the FIFRA in 1978 caused an increased interest in the use of pivot and other overhead irrigation systems for insecticide application since it allows the application of insecticide with any application method not prohibited on the label. Farmers saw that they already had equipment that gave them control of application timing, allowed applications to be made during irrigations, and also amortized high priced equipment through other uses.

Interest in chemigation also was spurred by the labeling and subsequent sales and promotion activities of the 4E formulation of chlorpyrifos. Carbaryl, previously labeled for application with irrigation systems, was not as easy to use as Lorsban 4E nor was it recommended for corn in the Corn Belt. Many farmers who produce corn on coarsely textured soils have used their overhead irrigation systems for application of liquid fertilizers, particularly nitrogen. For the application of N_2, farmers have installed large volume injector pumps on fiberglass tanks for their pumping systems. The Nebraska law requires that for chemigation pivots must have a working

check valve in the main water line to prevent back-flow of chemicals into the well. Such a valve is designed to protect the aquifer or any source of water from contamination.

Farmers wanting to "insectigate", have a wide range of equipment in variable states of repair. Most farmers have not had their wells and pumps checked since their installation. Farmers may believe the well is putting out 1,000 gallons per minute when it is pumping only 600-700 G/m. Farmers also haven't recently checked the system for its ability to give a uniform application, an important consideration not only for uniform chemical application but also for efficient water use.

We recommend to any new farmer who wants to chemigate to have his pumping plant center-pivot system checked for uniform water application. We also urge him to not only comply with the law in having a back-flow check valve in place, but to install interlocking systems that will shut off the pivot system if the injector fails, or vice versa. We also suggest a vacuum-breaker on the main irrigation line to further protect against back-flow of chemicals and that the injection port be placed on the vertical stand-pipe of the pivot above the chemical tank.

Further, depending on the chemicals (insecticides or herbicides) to be used, national fire and electrical codes contained within the OSHA law may require explosion-proof wiring and steel chemical tanks.

The farmer also needs equipment for agitation of suspended insecticide formulation in the chemical supply tank. A farmer buying a new, complete, injector unit will probably find the equipment (paddles and motors) already supplied for agitation in the tank. To use his unit to its greatest potential, strong agitation must be available. An air pump agitator bubbling large volumes of air through the solution from the bottom of the tank is one of the simplest agitators. However, even an electric trolling motor mounted on the top of the tank can provide mechanical agitation.

Once the farmer is certain that he knows his water volumes at a given power setting and safety protections are in place, then he can be taught to determine how to apply an insecticide through his system, even without using the relatively low volume injectors currently available.

For any injector and tank to be used for chemigation, the volume pumped by the injector from the chemical tank must be calibrated for each chemical that is to be used. Viscosity varies from one material to another and thus the volume may vary from one pump type to another. Filling the chemical tank with the mixture to be used, then running the injector pump for a measured period of time, catching and measuring the volume pumped, will produce an approximation of the value needed for injection. But even further checking on pump output must be done as the insectigation begins because injector pumps will be working against the pressure of the water going through the main water line.

As injector systems (pump, tank and safety devices) have become more sophisticated, simple by-pass volumetic calibration devices have become part of the units. And, many farmers in our area are buying these injector systems/units, placing them on trailers to use with several pivot systems. Others who have been insectigating for several years are placing permanent injector systems at every well and pivot system, so that they may chemigate all fields at the same time, if need be.

The other bit of knowledge necessary for chemigation is the exact amount of time it takes for the pivot system to make a complete revolution and the radius of the circle irrigated during that revolution.

Once the chemical to be used, the volume of the injector, the radius of the circle being irrigated, and the velocity of the pivot system to be used are known, it then becomes a matter of simple mathematics to determine how much water, or other diluent, and chemical should be added to the supply tank to apply the labeled amount of chemical per acre.

For new insectigators, safety for the environment, the user, and those who might have business in a field being treated, are of primary importance. If this aspect is not given top priority, regulations may be imposed that will essentially eliminate chemigation, a very important application method, from our arsenal. Certainly there will be more regulation in the future than there is now. A model law is currently being prepared for states to introduce in coming legislative sessions (Berry 1984). That model law is primarily aimed at safe use of center pivots for chemigation. But, abuse and environmentally unsound use could send chemigation back to oblivion.

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INSECTIGATION TRIAL FOR CONTROL OF THE SOUTHWESTERN CORN BORER, DIATRAEA grandiosella (DYAR), ON FIELD CORN IN THE HIGH PLAINS

by

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INTRODUCTION

The use of pivot sprinkler irrigation systems for irrigation of field corn and other crops in the High Plains of Texas and New Mexico has seen a remarkable increase in the last decade. The center pivots have aided the farmer in better use of water and have reduced irrigation cost. But, since 1977, they have become an increasingly promising means for applying farm chemicals. Insecticides, particularly, have proved to be effective when applied through a pivot irrigation system. The facts that make this method attractive are increased insect control and a significant reduction in cost per application for the farmer.

In an effort to examine the qualities of insecticides applied through a pivot irrigation system (insectigation), a field trial was organized through FMC Chemical Division, Shell Chemical Company, and Sandy-Lands Crop Consulting and Research. The trial was designed to evaluate control of the Southwestern corn borer, Diatraea grandiosella (Dyar) on field corn.

The objectives were to:

1. Compare insect control efficiency by insectigation with that of conventional aerial techniques.

2. Evaluate two pyrethroid insecticides and two carriers for control efficiency through insectigation.

METHODS AND MATERIALS

The experiment was conducted on two 48.5 hectare sprinkler-irrigated circles of field corn (Pioneer 3186) The plant population was 69,000 plants/ha on 0.76 meter rows. These circles were adjacently located on the Traveling Waters Ranch southwest of Clovis, NM. Each circle was equipped with "Raincat" sprinkler systems with 1.2 m drops with cone type sprinklers. The low pressure systems were maintained at 22 psi for 2838 L/min. Each sprinkler was calibrated to deliver 24 mm water/ha for an 82.5 and 69.6 hr complete circle for pivots I and II, respectively. Each pivot had a Milton-Roy diaphragm-type injection pump Model 111.730 with a 1.4 gal/hr maximum flow and a repetitive accuracy of 99.75%. Each pump was also equipped with a 208 L polyethylene mixing tank for correct carrier-chemical mixtures.

The experimental design consisted of a randomized complete block. Five insecticide treatments plus an untreated check were compared. Four of the

treatments were insectigated--Pounce 3.2 EC at 0.11 kg AI plus 9 L-water/ha; Pounce 3.2 EC at 0.056 kg AI plus 2 L-Cottonseed oil/ha; Pydrin 2.4 EC at 0.11 kg AI plus 9 L-water/ha; Pydrin 4 E at 0.11 kg AI plus 2 L-Cottonseed oil/ha and one was aerially applied Furadan 10G at 1.12 kg/ha. Each circle was divided into 4 hectare pie-shaped plots with each pivot receiving two replications of each treatment. The test was begun July 4, 1983. Insecticide-carrier efficiency data were taken at 2, 10, and 96 hours after application. Twenty infested plants (characterized by whorl damage) were sampled/plot/time interval. This entailed dissecting each plant individually to observe southwestern corn borer larvae. The number of dead and live larvae was recorded.

RESULTS AND INTRODUCTION

The single application of insecticides through the sprinkler system gave very effective control of the southwestern corn borer (Table 1). Results are given in percentage reduction from the untreated check and in mortality of all the larvae found in sampling. No significant differences (P=0.05) could be shown for either insecticide treatment or in the carrier used for application. Pounce gave numerically better larval control than Pydrin, and both gave significantly better larval control than the check. No significant difference in larval mortality for Pounce at 0.05 with the oil carrier and at 0.1 in water could be shown, possibly indicating that the oil enhanced insect control with the half rate. The addition of the non-emulsified oil to the Pydrin increased control of larvae, reducing the number of infested plants by approximately 18% and increasing mortality of larvae

TABLE 1. Mean % reduction in infested plants and mean % mortality of Southwestern corn borer larvae infesting Pioneer 3186 field corn treated with insecticides in irrigation water and by air.

		Mortality at no. hours post treatment[a/]		
		2	10	96
Insecticide/ Carrier	Rate kg AI/ha	% Reduction	% Reduction	% Reduction
Insectigated				
Pydrin 2.4EC/H20	0.11	61/40A	67/44A	67/48
Pydrin 4E/oil	0.11	69/59A	79/70A	77/68
Pounce 3.2EC/H20	0.11	75/61A	81/74A	92/86
Pounce 3.2EC/oil	0.056	72/54A	81/74A	91/84
Aerial				
Furadan 10G	1.12	-	-	71/56

[a/] Means followed by the same letter are not significant at the P=0.05 level.

about 10%. However, neither compound with the oil additive significantly increased larval mortality over that with only water added, even though Pounce was used at twice the AI/ha with the water. Furadan granules applied by air resulted in a significant reduction in number of infested plants and in percent larval mortality, but control was not significantly different from the insectigated treatments.

Insectigation is a viable method of applying insecticides for the control of the Southwestern corn borer, with an oil additive potentially increasing the performance of compounds and possibly lowering the rates of compounds needed for effective control of the SWCB.

CHEMICAL INDUSTRY'S ROLE IN CHEMIGATION

by

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The chemical industry has had a long and varied role in the history of chemigation. During the 1970's, researchers from the Stauffer Chemical Company coined and trademarked the term "Herbigation" to specify the application of herbicides through irrigation water. Various other companies then began investigating the feasibility of using their compounds through furrow or overhead irrigation systems. The method was shown to provide excellent uniformity of chemical application and deposition when the water was not a limiting factor. Following the herbicide experience, it was only a matter of time before insecticides were tried through irrigation systems.

Union Carbide began in the mid-1970's to apply Sevin through overhead sprinkler systems. During the late 1970's and early 1980's we, at Dow, began to look at chemigation as an alternate method for delivering Lorsban 4E insecticide to crops. Dow's experience with chemigation serves as the basis for this talk.

As the basic supplier of Lorsban, an excellent crop insecticide, Dow is anxious to offer as much flexibility in application requirements as can be given within the bounds of good product stewardship. Hopefully, the grower can then select application methods encompassing variables, such as available equipment, crop, type of pest, climatic conditions, etc., that will optimize the return on the investment for pest control. Dow views chemigation as an important third application option for the farmer. It deserves equal status with ground or aerial application technologies. With all of these methods, Dow is committed to encouraging applications that are consistent with good product stewardship and optimal results for the farmer. For every crop, there are at least two options for each situation encountered that will dictate the application method recommended. In many situations involving chemigation, the choice will be obvious; if a product cannot be used in the manner specified in its use labeling and literature, Dow will recommend against its use. For example, for Lorsban 4E + oil applied through center-pivot systems, specialized equipment to safely handle the product is a legal necessity. Properly functioning anti-siphon and vacuum relief valves are required in the irrigation pipeline between the irrigation pump discharge and the injection port on the center-pivot irrigation line to guard against back-siphoning. Dow also suggests that the use of a second anti-siphon valve with a solenoid valve be opened when pressure is off, so the system will bleed any material that passes through the first anti-siphon valve. This further assures that insecticides do not run back into the water source. The irrigation pump and the chemical injection pump must be interlocked so that if the irrigation pump stops, injection of the insecticide also will cease. A positive displacement pump designed to inject low volume insecticide accurately is necessary for many applications. A properly functioning check valve is required in the chemical injection line to stop

the flow of water from the irrigation system into the chemical supply tank. A calibration tube is required to properly meter the insecticide. Dow does not want its chemicals used when wind speed or direction would result in unacceptable drift from the target area, or where runoff could collect and pose a hazard to livestock, wells, or adjoining crops.

Dow is dedicated to working in whatever way it can to assure that adequate safeguards are incorporated in a chemigation system to prevent loss of a valuable delivery system through faulty use. When used properly, chemigation can be an efficient and effective way for delivering pesticides.

Dow is committed to the safe handling of its products. With this in mind, Dow has a continuing program to evaluate human exposure risks from all application methods. Before labeling Lorsban 4E for this use, Dow looked at scout reentry times for treated fields. Reentry on a daily basis was safe upon drying of the plants. Catastrophic one-time exposure to pivot spray had a five-fold safety factor and wet plant exposure had a ten-fold safety factor below the no-effect level.

Based on Dow's studies, chemigation with Lorsban 4E and non-emulsified crop oil is an efficacious and economical method for insect control in a variety of crops. At present, Dow has chemigation data for corn, cotton, peanut, alfalfa and sorghum. Growers have been satisfied with the application flexibility and activity levels of chemicals applied by chemigation. It behooves all of us to work toward adherence to the basic equipment requirements so that recommended methods for chemigation can continue to realize the potential as another major method for pesticide delivery.

THE CENTER PIVOT INDUSTRY'S ROLE IN CHEMIGATION

by

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INTRODUCTION

The center-pivot, sprinkler irrigation machine has been in existence for 36 years. It was invented in 1948 by Frank Sybach, an eastern Colorado farmer. The first machines were manufactured in 1952 at Columbus, Nebraska. Manufacturing rights and patents were purchased by Valmont in 1953, with the first system produced by Valmont in 1954.

Early center pivots had the pipelines suspended by cables and were powered by water hydraulic cylinders. The cylinders in turn operated trojan bars that engaged lugs on the system's steel wheels for advancing the machine through the field. Each stroke of the hydraulic cylinder moved the machine forward by 15 cm.

Many types of drive mechanisms were tried for center pivots including oil and air cylinders plus water turbines. Another innovative type of drive was powered by an oscillating cable that drove "walker-type" pads so that the towers walked ahead instead of rolling on wheels. In the middle 1960's, electric-powered drive trains began to appear on center pivots. Chain drives were the first type used followed by worm gear drive trains, which remain the most popular because of their self-locking feature. Planetary oil and electric drives also are used on center pivots, with the oil-powered type used in the field the longest period of time.

The method of supporting the pipeline has varied over the years, with both cable suspension and bridge truss designs used. Most systems now use a bridge undertruss design (bowstring, Warren, Howe, etc.) with a flex joint at each tower so that the spans can more easily negotiate rough ground.

Until 1973, all center-pivots suffered from an inability to irrigate non-circular areas. A standard-sized quarter section machine cannot irrigate 10-12 hectares out of a 65-hectare field. In response to this basic limitation, Valmont developed a steerable corner system in 1973, which allowed an additional 7-10 hectares to be irrigated by the mechanically movable irrigation system.

Even with the corner system, there were certain fields that remained hard to irrigate because of their shape. In the late 1970's, linear machines that moved in a straight line were developed to irrigate rectangular fields. Fields with a 2:1 length-to-width ratio are best adapted to linear machines. Water supply to linear machines can be by ditch, hose, or enclosed pipelines.

Since 1954, Valmont has sold over 50,000 machines in the U.S. and foreign countries that irrigate ca 2,023,000 hectares. Industry-wide, from 4 to 4.1 million hectares of the U.S. farmland are under center-pivot irrigation (Gold et al. 1984). Normal center pivot length is usually 400 meterss (8 towers) for use on a square 65 hectare field. Extreme lengths range from three tower (16 hectares) machines or less to 800 meter machines to fit an entire section and irrigate approximately 202 hectares out of 259 hectares. The maximum length pivot in the U.S. is 1016 meters (28 towers - 338 hectares) with a 1150 meter machine in South Africa being claimed as the world's longest.

HOW A CENTER PIVOT OPERATES AND ITS ASSOCIATED COSTS

Why has the center pivot become so popular? Frankenstein (1976) listed the reasons for the center pivot's popularity: labor savings, precise water distribution (both quantity and uniformity), its adaptabilties to sandy soil and rough terrain, its highly automated push-button control, its reversibility; and a continually moving system. Perhaps the main reasons for its wide acceptance has been its versatility, labor savings, and highly uniform water distribution patterns. No other mechanical moving system can claim such a high degree of uniform water distribution.

The center-pivot system's speed is normally controlled by the time it takes the end tower to run during a given period, like one minute. A percentage timer at the pivot controls the time the outer tower runs. At full speed, the outer tower runs 100% of the time. If the speed is to be cut in half, the timer setting is reduced by 50% so that the outer tower will run one-half of the time, e.g. 30 seconds out of a minute.

Each inner tower has an alignment mechanism that senses the movement of the outer span of pipe. If the outer span of pipe moves far enough ahead, the next tower will sense the movement and begin to run ahead to regain its aligned position. The alignment signal will work its way toward the pivot, causing different towers to advance the system around the field. If a particular tower gets too far ahead or behind the rest of the machine, a safety switch exists at each tower to stop the machine and the irrigation pump.

On normal center-pivots, all towers have the same speed drive train powered by an electric gearmotor (normally 0.75 kilowatt). Normally, a 400-meter system will make a revolution in ca 22 hours at 100% outer tower movement. High speed pivots have less gear reduction at the gearmotor and are capable of a complete revolution in 11 hours. Higher horsepower motors are required for faster machines (normally 1.1 kw) since the gear reduction is less; but the same amount of torque is required.

Water application per pass over the field is controlled by: system speed and liters delivered by the water pump. A standard pivot delivers 3400 LPM (liters per minute) for a 53 hectare, quarter-section machine. Water application per pass can be calculated by the following steps:

1) LPM/hectares = $\frac{3400}{53}$ = 64 LPM/hectare

2) Application/Day = 64 LPM/hectare X 0.146 = 9.32 mm/day

3) Application/Revolution = $\frac{\text{mm/day}}{\text{24/hr/day}}$ X hr/rev

3.1 Standard Speed (22 hr/rev)
Application/Rev = $\frac{9.32 \text{ mm}}{24}$ X 22 = 8.5 mm/rev

3.2 High Speed = (11 hr/rev)
Application/Rev = $\frac{9.32 \text{ mm}}{24}$ X 11 = 4.27 mm/rev

The application/revolution values obtained in Step #3 were for 100% machine speed. On the standard machine, changing the timer to 33% would apply 25.5 mm/pass; while on the high-speed machine setting the timer at 33% delivers 12.8 mm/pass. For a 3400 LPM system with 74 m total head, a 56 kW electric motor is required to pump the water. Assuming the pump motor is 88% efficient and electrical costs are $0.07/kWH, it would cost $4.45/hr to pump 3400 LPM. An eight tower center pivot with a 1.5 kW booster pump and eight 0.75 kW motors requires about 14.14 kilowatt (kW) per hour to operate the center-pivot system. Thus, a standard-speed machine and 75 HP pump would require $5.44/hr total to run. If it takes 22 hours to make a revolution, a total cost of $119.68 would occur, or a cost of $2.27/hectare. As noted before, 8.5 mm of water would be applied. The high-speed machine has up to three 1.1 kW motors that require 15.85 kW to operate, at a total cost of $1.11/hr. However, high-speed machines made a revolution in 11 hours, so the total cost per hectare would be only $1.16/hectare. Again, as mentioned before, the water application would be 4.27 mm per system pass.

Irrigation equipment costs play a large part in determining whether it is economically feasible to irrigate. Development costs for our example (3400 LPM - quarter section machine requiring a 56 kW electric motor in a 60-m well) would be approximately $9.24/hectare depending on the location in the U.S. In addition to the equipment costs, operating costs of the irrigation system have determined the pipe sizing, water application equipment, etc., for center pivots.

Operating costs of a center pivot are determined by two basic components: cost of operating the electric pivot system and the cost of pumping the water. Total system operating costs per revolution will depend on how much water is applied and the operating pressure (kPa [kilopascal]) of the center pivot.

Trends during the past 8-10 years have been to reduce the pumping costs by lowering the pivot pipeline pressure. For our example, the kilowatt (kW) requirements with a 7.6 m field elevation difference, a pumping depth of 38 m and a gallonage of 3400 LPM would be: 73.7 brake kilowatt (BkW) with high pressure impacts (414 kPa pipeline pressure at end of system) used 10 years ago, compared to 55.3 BkW for spray nozzles having 138 kPa pipeline pressure

at the outer end of the system. This amounts to a 25% (18.3 BkW) power savings.

Spray nozzle packages are currently available that use 69 kPa pipeline pressure at the end of the machine, but their applications are limited to sandier, fairly flat terrain. The 69 kPa package reduces BkW to 36% (47.4 BkW) of the standard high pressure impact sprinkler packages.

There are other intermediate-sprinkler packages that reduce the system pressure from the 414 kPa to about 207 kPa while maintaining the wider wetting pattern of the impact sprinkler. Special nozzle shapes are used to break up the water droplets so that impact sprinklers can perform satisfactorily at pipeline end pressure of 207 kPa. These sprinkler packages are more adaptable to rolling terrain and heavier soils. Variable-spaced impact sprinklers with low angle trajectories that fight drift due to wind are available with 345 kPa pipeline end pressure. Pattern overlap is increased with the variable-spaced systems that improve water uniformity.

The ratios of nozzles sold lately has been 75% spray (69 to 138 kPa) and 25% impact (207 to 345 kPa). This ratio has resulted from energy savings gained from the spray nozzle packages.

CENTER PIVOTS AND CHEMIGATION

Liquid urea fertilizers were first applied through Valley pivots near the Valmont plant in 1957. Research involving the application of commercial fertilizer through a sprinkler irrigation system was begun in 1958 (Threadgill 1984). The acceptance of fertilizer (nitrogen) application through center pivots resulted in the new technology of chemigation - the application of chemicals (herbicies, insecticides, fungicides, nematicides, etc.) through a center pivot by injecting the chemical into water flowing through the system (Threadgill 1984). Insectigation work in Nebraska began in 1975 with treatment of corn ear worm (*H. zea*) in seed corn (Medders 1984).

Advances in both center-pivot design and chemical injection equipment led researchers to develop new chemical insecticide formulations that work in large volumes of water. The addition of non-emulsifiable crop oils as a sticking agent further improved the effectiveness of the chemical by increasing its residual effect. For instance, in Nebraska alone during 1983, about 121,000 hectares of corn were treated for European corn borer using new chemical formulations with and without oil additives. (Gold et al. 1984). Thus, about 9.5% of the total 1.3 million hectares under center-pivot irrigation in the state (24,410 center pivots) were treated for European corn borer control.

Nationwide in 1983 about 46% of the total sprinkler irrigated hectarage (including center pivots) was chemigated at least once, mainly by fertigation (34%). This equalled 3.9 million hectares of 8.9 million hectares being chemigated. The growth rate for chemigation appears to be about 8-9% per year (Threadgill 1984). The potential growth rates for uses other than for fertigation appear to be even higher if usage increases as insectigation has in Nebraska the past couple of years.

Why has chemigation begun to catch on at such an accelerated rate? One of the main reasons is that chemigation provides the farmer with a crop management tool that has many advantages when it is properly utilized. The advantages of chemigation are:

1) Center pivot provides excellent uniformity of chemical application. Heikes (1981) compared the efficiencies of applying herbicides:

    1.1) Center Pivot: 85-92%
    1.2) Ground: 70-90%
    1.3) Air: 60-90%

2) It allows prescription application of chemicals only as needed.

3) It allows timely application of chemicals.

    3.1) With center pivots, chemicals can be applied day or night under variable weather (however, chemicals should not be applied when the wind is over 16-19 kilometers per hour (km/h), regardless of the application method used).

4) It allows easy and effective incorporation and activation of chemicals. Water provides a means for not only activating the chemical but also for incorporating it into the soil.

5) It reduces soil compaction by eliminating trips across the field by heavy implements. This becomes more important in crops requiring numerous chemical applications during the year.

6) It reduces mechanical damage to crops. For instance, crops like peanut are very susceptible to injury by wheeled traffic late in season when fungicides need to be applied.

7) It reduces operator hazards by not having an operator on the spray rig applying chemicals.

8. It may reduce chemical requirements.

    8.1) Chemicals used for European corn borer control penetrate the crop canopy to the corn whorls with increased water volume where the pest occurs (60+% in corn whorl with chemigation vs less than 40% with aerial application) (Threadgill 1984).

    8.2) Nitrogen fertilizers are subject to leaching. If applied in smaller amounts throughout the growing season, there are less materials to leach into the soil during heavy rains.

9) It has a potential for reducing environmental contamination.

    9.1) Low pressure spray nozzles on center pivots reduce chemical drift caused by wind.

9.2) The parts per million (PPM) concentration of chemical in the water are much less with chemigation than with aerial spraying (Qualls 1984). For example, consider 1.75 L/ha of chemical applied with 4.27 mm/ha of water through a center pivot vs 2.3 L/ha of chemical in 93 L/ha of water with aerial spraying.

9.2.1) With the center pivot there would be 40.6 PPM of chemical where aerial spraying would provide 25,000 PPM of the chemical.

9.2.2) Therefore, the compounds applied by aerial spraying would be over 600 times more concentrated than the compounds applied by the center pivot, but pest control results are as good or better with center pivot.

These potential management advantages, coupled with the favorable economics of chemigation, have led more farmers to try it. With proper equipment and accurate calibration, chemigation via a center pivot is safe, effective and economical.

ECONOMIC COMPARISONS IN NEBRASKA

The expenses chargeable to chemigation depend on whether or not the farmer needs to irrigate. For our example, the operational cost is assumed to be associated with chemigation and not irrigating. While the cost of operating a center pivot, an aircraft, or a ground rig depends on many factors, the data in Table #1 reflect the general costs for pesticide application in Nebraska during 1984. The costs are based on chemigation for European corn borer control using Lorsban 4E with non-emulsifiable crop oil through a 3400 L/m, 53 ha center pivot with electrical costs of $0.07/kWH to operate a 56 kW irrigation pump and an eight tower pivot. All fixed costs of the equipment and electrical stand-by costs are assumed to be borne by irrigation usage of the equipment.

After reviewing the costs in Table #1, it becomes evident that the high per-hectare cost for chemigation is tied to the quantity of chemical and oil used. Some farmers claim that a reduction to 1.1 L/ha of chemical plus 1.1 L/ha of oil does not lessen control of the ECB. If this is true, chemical costs are reduced to $10.50/hectare. This cost would result in a savings of $2,514.46 per standard-speed revolution of a pivot system for our example, compared with the cost of an aerial application. Obviously, a farmer is very interested in knowing how little chemical can be used and still get the job done with chemigation.

An additional factor in chemigation is the cost of the equipment itself. This cost is variable, depending on the type and size of the injection pump, agitation equipment, tank, calibration tube, chemical line check valve, and plumbing hardware that is used.

Table 1. Relative costs for center pivot chemigation and conventional Methods of Insecticide application for control of the European corn borer.

Description	Center Pivot		Aerial	Ground	Center Pivot (with equip-Rental)	
1) Chemical ($/ha) @ $7.93/liter	1.75 L for $13.91		2.35 L for $18.53	2.35 L for $18.53	-- --	
2) Crop oil (non-emulsifiable - $/ha @ $1.06/L	2.35 L for $2.47		--	--	--	
3) Total Chemical $/ha	$16.38		$18.53	$18.53	--	
	Standard	High Speed			Standard	High Speed
4) Application Cost $/ha	$ 2.27	$ 1.16	$13.59	$ 7.41	$ 2.27	$ 1.16
5) Equipment Rental + Chemical + Monitor $/ha	--	--	--	--	$ 24.71	$ 24.71
6) Total $/ha	$ 18.66	$ 17.54	$32.12	$25.95	$ 26.97	$ 25.87
7) Chemigation Savings/ha vs aerial	$ 13.47	$ 14.58	--	--	$ 5.14	$ 6.25
8) Chemigation Savings/53 ha Field vs Aerial	$708.50	$767.00	--	--	$270.40	$328.90
9) Chemigation Savings vs Ground-1st Brood $/ha	$ 7.29	$ 8.41	--	--	$ 1.04	$ 0.07
10) $/53 ha	$393.90	$448.50	--	--	--	--

Another item to be considered is the mainline check valve and vacuum relief valve. In all probability the irrigation well already has a check valve, but its condition should be tested. If the pump check valve leaks and allows water to flow back into the well, it should be replaced with a spring-loaded, rubber-seated check valve having an inspection port and drainage fitting that can be attached to a hose for draining any leakage water away to a sump.

The safety interlock feature between the chemigation equipment and the center pivot will also cost some money. If the system shuts off, the chemigation equipment should also shut off, and vice versa. This can be accomplished with interlocking safety circuits between the two systems. The flow sensor in the chemical pump pressure line can be used to monitor flow, and if none exists, the sensor can shut the center pivot down. If the center pivot shuts down, the center pivot safety circuit will drop out and stop the chemigation pump.

Finally, options like high-speed pivot equipment and trailers for chemigation equipment might be considered. These options would probably make it possible to use the chemigation equipment on more than one pivot with three to five pivots being the maximum recommended number used (Medders, 1984; Raun 1984). A chemigation unit should be as portable as possible and have a quick disconnect on the chemical line and plug-in connectors. Electrical safety interlock equipment can be supplied by center-pivot manufacturers. Chemigation equipment dealers are not supplying interlock equipment because of the different center pivot control panel configurations.

Table #2 gives average costs for equipment available for European corn borer control in Nebraska during 1984. From Table #2, it can be seen that

Table 2. Chemigation equipment costs for control via insectigation of the European corn borer.

Description	Standard Speed		High Speed	
	Skid	Trailer	Skid	Trailer
1) Chemigation Equipment	$1750.00	$2065.00	$1750.00	$2065.00
2) 8" Mainline Check Valve	395.00	395.00	395.00	395.00
3) High Speed Option for Center Pivot	--	--	250.00	250.00
4) Two-Way Electrical Interlock	865.00	865.00	865.00	865.00
5) TOTAL EQUIPMENT	3010.00	3325.00	3260.00	3575.00
6) Operational Costs Savings of Center Pivot vs Aerial from Table 1.	708.50	708.50	767.00	767.00
7) Number of Rounds to Pay for Chemigation Equipment	4.2	4.7	4.2	4.7

chemigation equipment pays for itself after five rounds or applications of chemical. If chemigation equipment were used on three pivots with two applications each made per year, per pivot, the savings in pest control by chemigation would easily pay for the cost of additional chemigation equipment in one year.

FUTURE CENTER PIVOT EQUIPMENT AND ITS RELATION TO CHEMIGATION

Because chemigation is a relatively safe, economical, and effective way for applying chemicals for pest control, a rapid increase in this crop production management tool has occurred throughout the U.S. As research efforts increase in chemigation, manufacturers must continue to update their equipment to broaden the center pivot's use as a giant spray boom. A center pivot manufacturer is probably the best source for a safety interlock package between the pivot and the chemigation unit. Using flow sensors and/or pressure transducers allows the safety circuit to shut down when either the pivot or chemigation equipment malfunctions. Unfortunately, this type of safety interlock equipment as a complete package is not currently offered by center pivot dealers.

Increasing the rotational speed of center pivots from 11 hours/revolution for a quarter-section to lower hours/revolution is under consideration. Advantages for having faster pivots include:

1) Chemical application time for the operator is reduced (thus the time the center pivot operator has to pay attention to the chemigation process).

2) Chemical application can be concentrated in the early evening when insects are most active.

Reducing the revolution time to 5.5 hours/revolution for a 1/4 section should be easy to accomplish by changing the gear ratio of the centerdrive and by increasing the horsepower of the motor. For a 3400 Lpm (1/4) pivot, a revolution in 5.5 hours would permit chemical applications in as little as 2.0 mm of water. The reduction in water applied per revolution might also result in the use of less chemicals. As mentioned before, reduction in chemical used/ha would be the fastest way to reduce the costs of chemigation since chemicals are the highest-priced item in the operation.

Additional equipment expenses should not be much more for the super high-speed pivots than the current price for high-speed pivots, which cost roughly $250.00 for a 1/4 section unit. The higher horsepower motors will cost more than currently used motors.

A major advantage for using a center pivot for chemigation work is the highly uniform distribution of water that can be obtained. Center-pivot manufacturers need to be aware of the effect of increased system speed on water uniformity. Very low water application may cause unacceptable distribution of chemicals. This may be a more serious problem on systems with low pressure spray nozzles that do not have wide water distribution patterns.

The potential lack of uniformity in water distribution can be solved either by using sprinkler packages with wider distribution patterns, by mixing centerdrive gear ratios to get a smoother moving machine, or by using shorter time period timers. Valmont plans to test the above-proposed solutions by doing a computer simulation of the center pivot's distribution of water under various operating schemes that control the movement of systems. Actual field tests to measure the water distribution of a system will follow these simulations to verify selected center-pivot modifications. At the same time, we also plan to add a chemical with and without oil to monitor its distribution characteristics. This type of work can be carried further with the testing of different types of sprinkler packages at different flowrates to vary pipeline velocities and the breakup of water droplets. Researchers have identified these factors as having an effect on the uniformity of final chemical distribution.

Other types of mechanically movable irrigation equipment will require additional equipment. For corner systems or systems with volume guns, more work is needed with variable rate injection equipment that will better match the chemical output with the volume of water discharged. The chemigation equipment on linear systems should probably be self-contained (mounted on the linear machine) so that in the ditch, hose is not treated but only that in the pipeline.

FUTURE ACTIONS TO KEEP CHEMIGATION GROWING AS A VIABLE INSECT MANAGEMENT TOOL

Chemical formulations must be tailored to fit specific needs of a farmer. Formulations may have an effect on the design of future pivots. And, of course, improved formulations may play a role in reducing chemical dosages need by chemigation.

Another key component in future pivots will be safety standards for protecting both ground and surface water sources. Safety data is needed to convince the non-farming public that chemigation is safe and poses no danger to them. All involved parties: universities, governmental agencies, chemical companies, chemical dealers, center-pivot manufacturers and dealers, chemigation equipment dealers, etc., need to educate the farmer and the general public on the chemigation safety equipment necessary to prevent ground water pollution.

In Nebraska, the Cooperative Extension Service has a task force developing educational materials for applying pesticides through irrigation systems. A Natural Resource District (NRP) (Upper Republican) in Nebraska has developed rules and regulations for insuring safety while using chemigation equipment. The NRD requires a yearly permit and an annual inspection of the equipment for chemigation activities. Failure to comply with these requirements results in forfeiture of 50% of the operator's ground water allocation. The Nebraska Department of Environmental Control has published a 400-page report for dealers and applicators that suggests certain uses for fertilizers and pesticides that need regulating. Irrigators using chemicals through center-pivots may be required to be registered.

Some states (GA, FL & WI) already have legislation governing the type of mainline check valve that is required for center-pivots used in chemigation. Other states are sure to follow with enforceable regulations. Dow Chemical and Valmont Industries have promoted chemical application through seminars on safety equipment necessary for chemigation. These seminars also have stressed proper calibration of equipment and methods for determining center-pivot speed, and chemigation equipment settings. Chemigation literature and seminars held by Dow and Valmont have helped make the farmer more aware of the opportunities and responsibilities involved with the use of chemigation.

Lobbying with the Environmental Protection Agency is needed so center-pivots can become recognized as a valid application method for farm chemicals as are aerial and ground application methods. Chemicals need to be registered for chemigation application. Label directions on the chemical container provide the best knowledge for safe and effective chemigation practices.

All involved parties need to emphasize:

1) Education and Training through equipment specifications, installation guidelines for safety interlocks, mainline check valves, etc., and chemical label recommendations.

2) Technical Support for proper chemigation equipment calibration and center-pivot speed and water application calculations.

3) Increased Public Knowledge by news articles and press releases to educate laymen on the uses of chemigation and its relative safety.

SUMMARY

Chemigation has provided the farmer with an expanding crop managment tool. It has increased the use of center-pivots for uses other than irrigation. Chemigation has provided a relatively safe, economical, and effective way of distributing chemicals on agricultural crops. With the proper safety equipment and calibration techniques, chemigation is no more, and probably even less, a threat to our natural resources than is the distribution of chemicals by ground or aerial application technology.

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METERING PUMP INDUSTRY'S ROLE IN CHEMIGATION:

CONSIDERATIONS IN SELECTING AND APPLYING CONTROLLED VOLUME PUMPS

By

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INTRODUCTION

This paper deals with controlled volume metering pumps, a specialized class of pumps used to add chemicals in precise quantities to a main process stream.

Some common applications of controlled-volume metering pumps are:

1) injection of liquid chemicals at very precise flow rates;
2) prevention or minimizing corrosion and scaling of vessels and piping caused by water;
3) adjusting or correcting the pH levels of aqueous process liquids;
4) assisting in the physical separation of suspended solid material from process liquids; and
5) modification or alteration of the character of process liquids.

Controlled-volume pumps typically involve electro-mechanical designs that convert high-speed rotary motion from a motor to low-speed rotary motion via a worm gear set, and conversion of the latter motion to low-speed reciprocating motion thru adjustable slider crank or eccentric mechanisms. The reciprocating motion facilitates the use of a variety of liquid ends to achieve pumping action (Figure 1a-c). Controlled-volume pumps are available as ductile iron, steel and stainless steels, including chromium and nickel-based super alloys. Various plastics also are used to manufacture controlled-volume pumps.

1. What Characterizes A Controlled Volume Pump

Controlled volume or metering pumps are characterized by accuracy, adjustability, pressure generating capability, and precise chemical handling range. A controlled-volume pump has a unique accuracy because it can deliver liquid at an average rate that varies by $\pm 1\%$ of set point over a wide range of operating parameters. Changes in discharge pressure of several hundred kPa, for example, will have little or no effect on accuracy.

Calibration accuracy is often important since the addition of too little chemical or liquid may produce inferior or undesirable results, while too much chemical can be unnecessarily expensive and produce undesirable results as well.

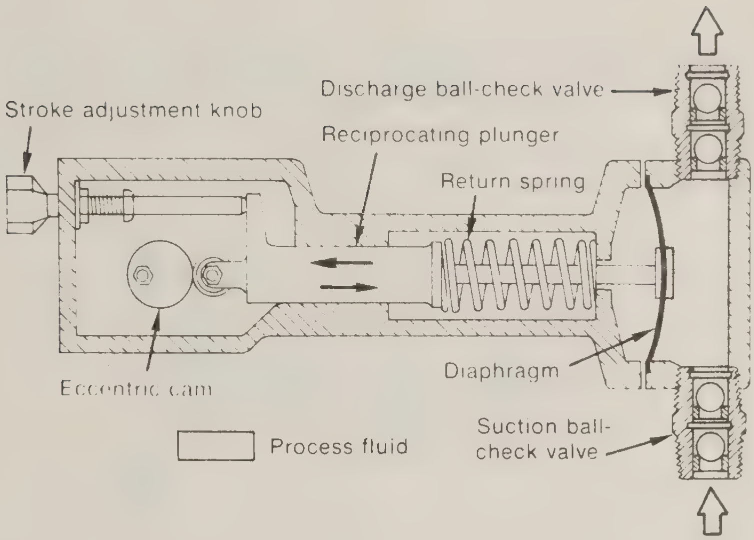

Figure 1a. Mechanical Lost-Motion Drive with Disc-Diaphragm Liquid End.

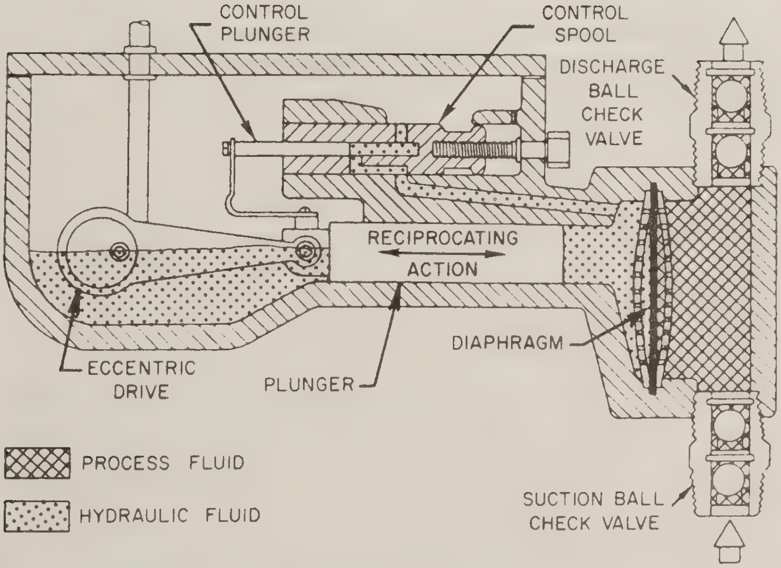

Figure 1b. Hydraulic Lost-Motion Drive with Disc-Diaphragm Liquid End.

Controlled-volume pumps have a built-in adjustment mechanism to permit flow rate changes from 0 to 100% of rated capacity. Output changes can be achieved by means of a micrometer-type manual control divided into 1% increments. Output changes can also be achieved with optional automatic

controls, both pneumatic and electronic. The ajdustment feature is particularly important in open- and closed-loop control systems.

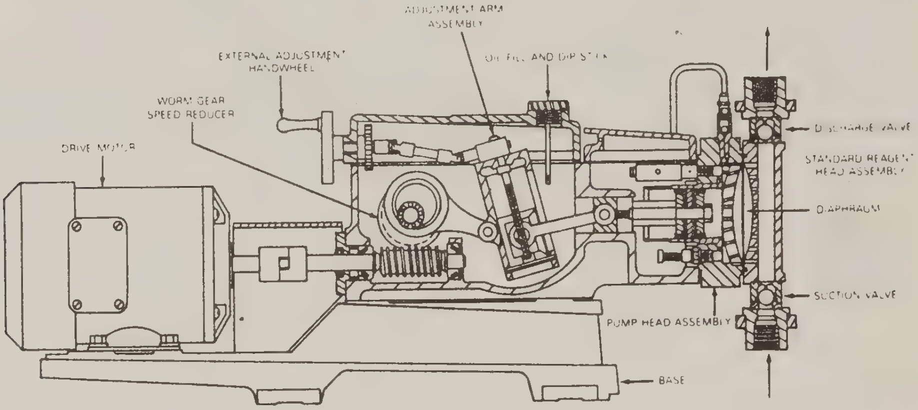

Figure 1c. Adjustable Slider-Crank Drive with Disc-Diaphragm Liquid End.

A turn-down ratio of 10:1 is common in most controlled-volume pump designs. Performance specifications are thus maintained between 10 and 100% of rated capacity. Of particular significance here are linearity and accuracy claims.

Off-the-shelf controlled-volume pumps are available for pressure-generating ing service to 51000 kPa. Special designs for service to 206000 kPa are offered by several manufacturers. High pressure capability is important in certain chemical reaction vessel-fed applications, as well as for supercritical fluid and liquified hydrocarbon pumping.

The fourth major feature of a controlled-volume pump is its chemical handling range. Depending on the design sub-class, everything from corrosives to highly viscous liquids and slurries can be pumped (Table 1).

Table 1 - Chemical Handling Range.

	Controlled-volume pump sub-class		
Chemical type	Packed-plunger	Disc-diaphragm	Tubular-diaphragm
Acid	P	E	G
Slurry	E	F-E	G
Viscous	E	F-E	E
Liquidfied hydrocarbons	P	E	P
High temperature	E	G	F
Radioactive	P	E	F
Sterile	G	E	E
Toxic	P	E	E

E = Excellent, G = Good, F = Fair, P = Poor

2. Typical Liquid End Designs

The basic operating principle employed in the liquid end (mechanism for pumping solution) of a controlled-volume pump involves fluid displacement resulting from the sweeping action of a plunger. Flow into and out of the pump is governd by check valve action. Characteristic performance specifications of the most common liquid end designs are shown in Table 2 and are described below.

Table 2 - Typical performance specification of various liquid end designs.

	Maximum SI[a]	
DESIGN	Capacity - L/h	Pressure kPa
Packed-plunger	11,355	51,705
Disc-diaphragm		
Mechanical lost-motion	757	1,034
Hydraulic lost-motion	379	12,400
Pressure-refill	56,775	24,129
Mechanical-refill	11,355	24,129
Tubular-diaphragm	2,838	6,894

[a] L/h = liters per hour, kPa = kilopascals

a. Packed-plunger

In the case of a packed-plunger designed liquid end (Figure 2), the liquid follows the reciprocating plunger. As the plunger moves rearward,

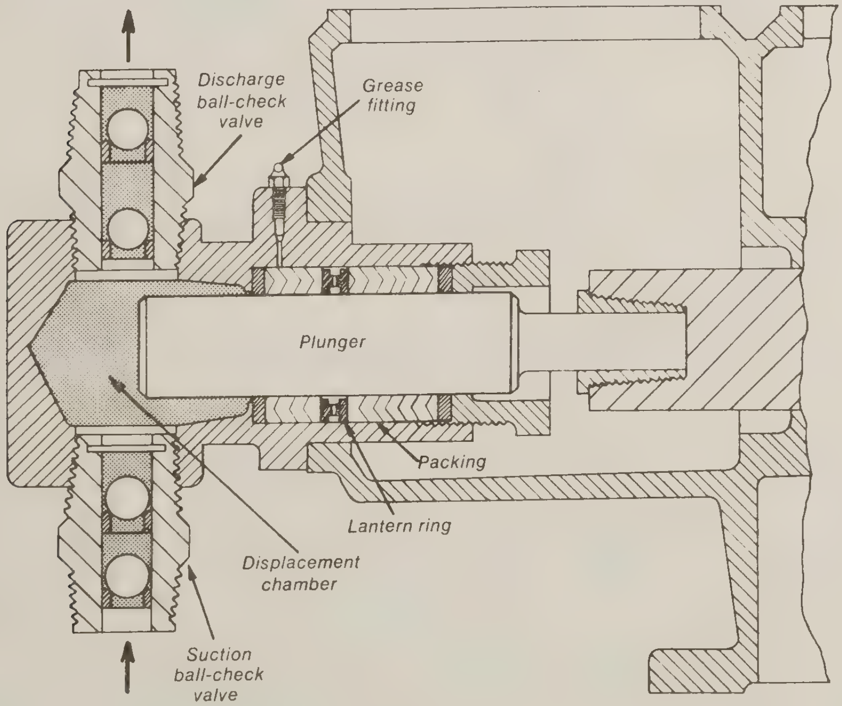

Figure 2. Packed-Plunger Liquid End.

liquid is drawn in thru the suction check valve; at the same time, the discharge check-valve is closed. As the plunger moves forward, pressure in the pump head increases and liquid flows out of the discharge check-valve. The suction check-valve is closed during the discharge half of the pump cycle. Flow rate is thus proportional to three variables: plunger cross sectional area, effective stroke length, and stroke rate.

Please note that the packed-plunger liquid end offers the best specification performance, inherent design simplicity, and economical cost. Periodic maintenance of the packing lubrication and adjustment is required. However, a slight leakage around the packing must be tolerated.

b. Disc diaphragm

Disc diaphragm designed liquid ends (Figures 1a-c, 3 and 4) are characterized by a flexible membrane, usually PTFE (polytetra-floura-ethylene), that separates the process liquid from the pump mechanism. The

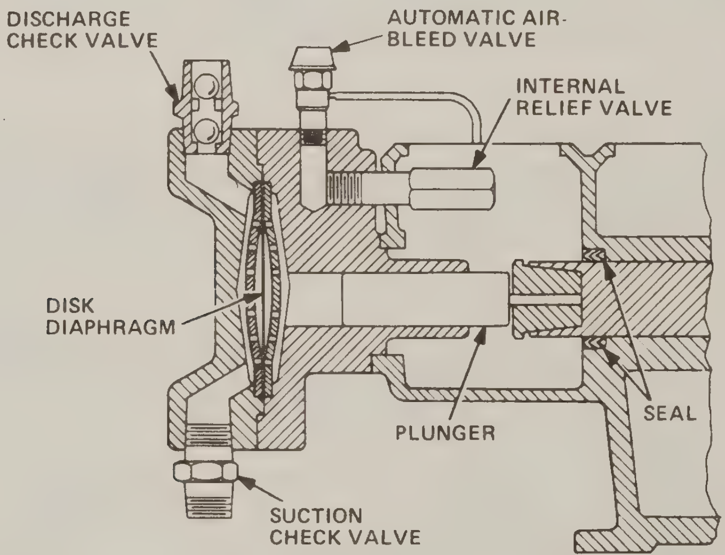

Figure 3. Disc-Diaphragm Liquid End.

diaphragm maintains a statistically-sealed barrier between the process liquid and the external pump environment.

(1) Disc-Diaphragms for Use with Lost-Motion Drives

Lost-motion drives may be either mechanical or hydraulic. In the mechanical lost-motion design, the diaphragm is directly coupled to the plunger (Figure 1a). A rotating eccentric cam reciprocates the plunger, which in turn flexes the diaphragm. Liquid is drawn into the pump by the diaphragm as it moves rearward, and is forced out when the plunger transports the diaphragm forward. These diaphragms, however, experience stress concentrations in clamping/fixation areas and are susceptible to failure caused by fatigue.

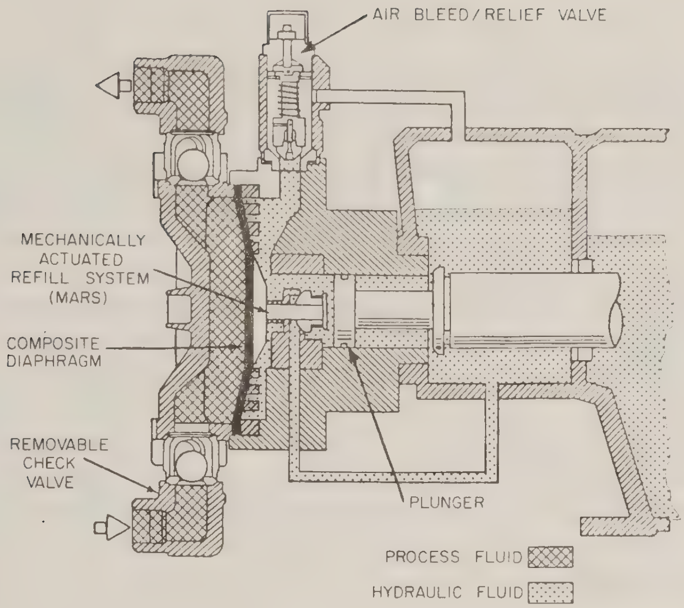

Figure 4. Disc-Diaphragm Liquid End with Mechanically Actuated Refill System.

An ideal design from the viewpoints of cost effectiveness and performance, and for the flow rates up to 378 Lph and at low to medium pressures, is the hydraulic lost-motion design (Figure 1b). In this design, the diaphragm is hydraulically balanced, with flow-rate adjustment achieved with a by-pass valve. Hydraulic fluid volume is made up at the end of each suction stroke as the by-pass valve momentarily opens, regardless of flow rate setting. This design has achieved a high degree of acceptance in chemigation/center pivot irrigation systems.

(2) Disc-Diaphragms for Use with Slider-Crank Drives

Hydraulically actuated disc-diaphragm designs used with adjustable slider-crank drives are of either the pressure or mechanical refill type. In hydraulically actuated devices, the diaphragm is caused to flex under uniform loading by a hydraulic liquid, with the liquid acted upon by the pump plunger (hydraulically balanced, as in the case of disc-diaphragm with lost-motion drives).

A three-valve system in the hydraulic liquid-loop insures fully automatic and unattended operation. The first valve, an air bleed valve, opens on each pump cycle to allow passage or release of any entrapped air from the displacement chamber (hydraulic cavity between diaphragm and plunger). The difference in pressure and mechanical refill types relates to function of the refill valve.

A pressure refill type system is shown in Figure 3. When enough hydraulic liquid has been lost from the displacement chamber through

air-bleed, relief valve and/or plunger-bore seepage, the flexing diaphragm migrates until it contacts the rear contour plate. If the plunger is continuing to move rearward when contact occurs, pressure in the displacement chamber decreases sharply. Refill valves then open at approxiamtely 62 kPa, allowing the hydraulic system to rebalance.

Mechanically actuated refill valves can only be opened when the diaphragm physically contacts the refill valve poppet. In this design, overcharge of the hydraulic liquid system is not possible, thus eliminating the need for a process side contour plate. Also, refill-valve operation does not occur until approximately 21 kPa is reached. Viscous liquids are more readily handled in such designs, and NPSH requirements are considerably reduced. (Figure 4).

c. Tubular-Diaphragm

The tubular-diaphragm liquid end (Figure 5) features a flow-thru design. Principal advantage of the tubular-diaphragm design is its efficiency in handling viscous liquids and liquids with a high solids content.

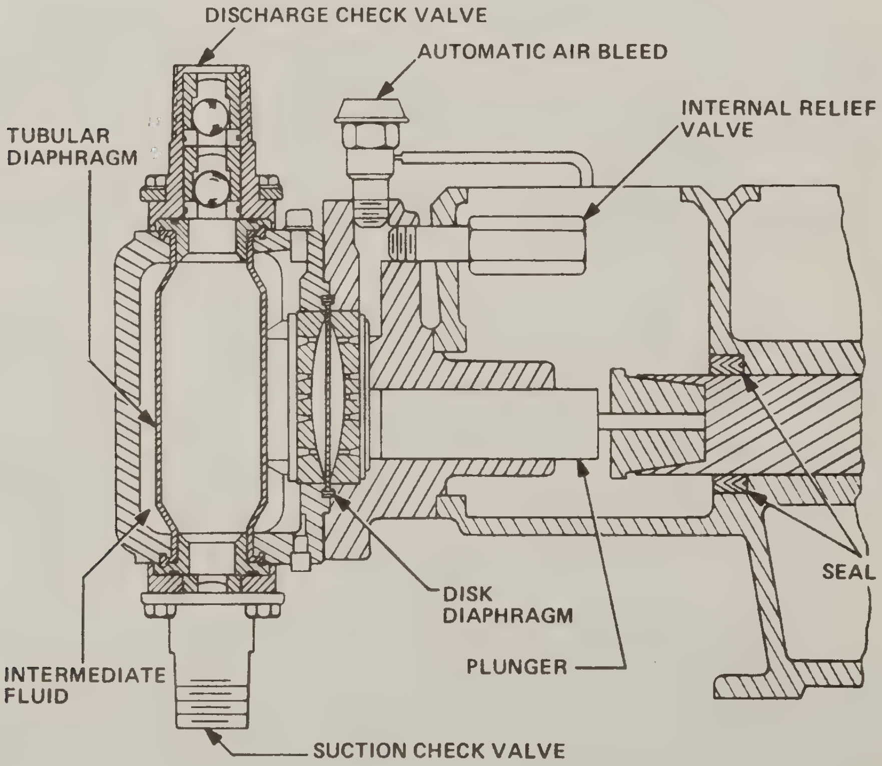

Figure 5. Tubular-Diaphragm Liquid End.

The liquid being pumped is contained within a tube, which is alternately squeezed and expanded by surrounding hydraulic liquid. A second diaphragm, which limits the amount of tube flexing action, is driven by

another hydraulic circuit. The primary mover is again a plunger, and a three-valve hydraulic control circuit with a pressure actuated refill valve is used.

3. System Design for Proper Pump Operation

Net-positive-suction-head (NPSH) available considerations, as well as accessory selection, are important and unique adjuncts to proper operation of a controlled-volume pump in a chemical-feed system. The discussion that follows is aimed at preventing most common start-up problems.

a. NPSH Available Considerations

The instantaneous flow characteristic in a controlled volume pump approximates a sine wave. Figure 6 shows characteristic flow at 100% and 60% of capacity setting in a pump with an amplitude-modulated (slider crank) drive.

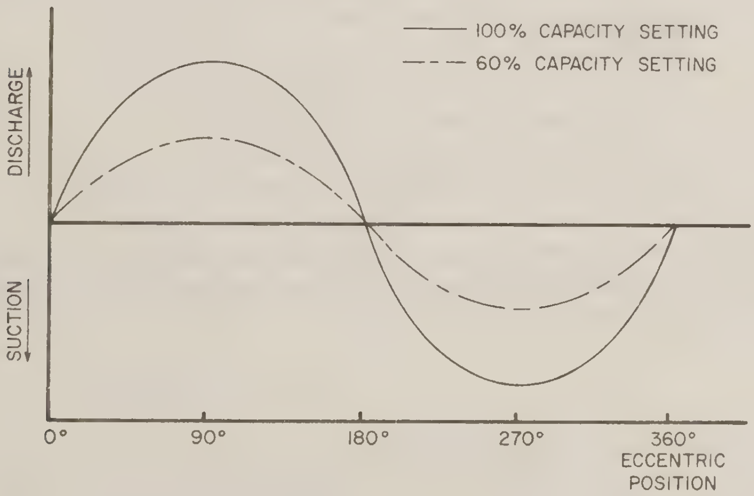

Figure 6. Sinusoidal-Flow Characteristic in Controlled-Volume Pumps with Amplitude Modulated-Drive.

Most start-up problems occur due to insufficient NPSH. Pressure loss in the suction line due to acceleration of the liquid between the tank outlet and the pump inlet at the start of the suction stroke is a dominating factor with water-like, low viscosity liquids, and high specific gravity liquids. Pressure loss due to velocity of the liquid in the suction line during the peak-flow demand portion of the suction stroke is a dominating factor with viscous liquids. If pressure losses due to either excessive velocity or acceleration of liquid in the suction line, NPSH is lowered until the pump is starved or liquid cavitates (flashes) on the liquid end.

Proper pump operation will occur when acceleration pressure losses dominate, if the folowing conditions are met:

(1) Pa +/- Ph - Pacc > Pv (packed plunger)

(2) Pa +/- Ph - Pacc > Pv or 62 kPa, whichever is greater (disc diaphragm, pressure-actuated refill)

(3) Pa +/- Ph - Pacc > Pv or 21 kPa, whichever is greater (disc diaphragm, mechanically actuated refill)

$$\text{where Pacc} = \frac{(S.G.)\ Lp\ T\ N^2\ D^2}{1.36\ (10^5)\ Dp^2}$$

$$\text{or Pacc} = \frac{(S.G.)\ Q\ N\ Lp}{2.76\ (10^4)\ Dp^2}$$

Pacc = Acceleration pressure loss (kPa)
S.G. = Liquid specific gravity
Lp = Actual pipe length (meters)
T = Plunger travel (cm)
N = Pump speed (stroke/minute)
D = Plunger diameter (cm)
Dp = Pipe I.D. (cm)
Q = Flow rate (liters/hour)
Pa = Pressure above liquid (kPa)
Ph = Liquid head (kPa)
Pv = Liquid vapor pressure (kPa)

Liquid head (gravity due to elevation above pump) is based on the lowest level in the supply tank, plus or minus the vertical distance from the plunger centerline (Figure 7).

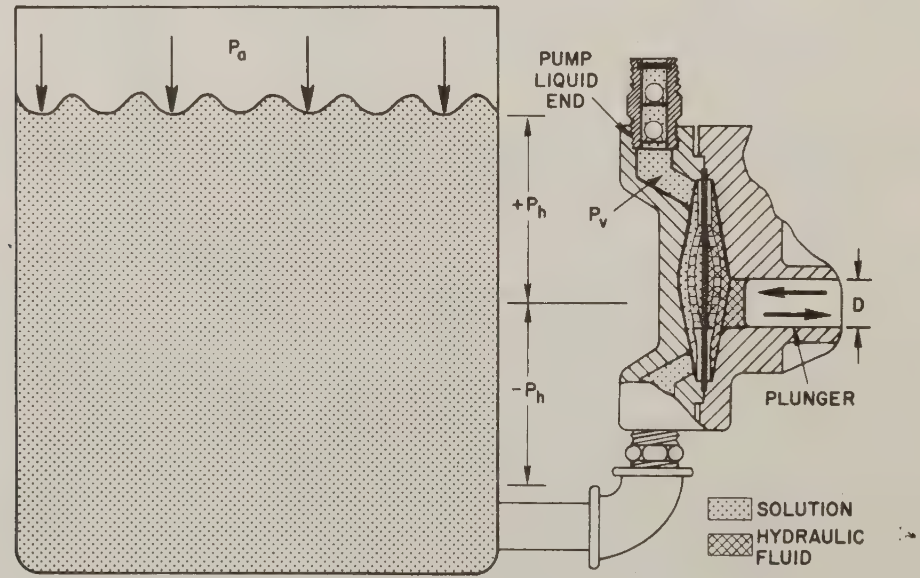

Figure 7. Net Positive Suction Head Considerations.

In the cases where velocity losses dominate, pressure drop in the suction system and the pump must be calculated based on peak flow, or 3.17 times average flow. Liquid viscosity contributes to the complexity of the pressure-drop equations. Total pressure drop is then substituted for acceleration pressure-loss in equations (1), (2), or (3) above to confirm that the system will operate properly under dynamic pumping conditions.

If calculations reveal unsatisfactory system design/pump selection, the following steps can be taken to reduce pressure losses at the pump head:

(a) Add a pulsation dampener to reduce flow surges associated with acceleration or velocity losses.
(b) Increase suction-line diameter.
(c) Use the next larger check-valve to lower pump pressure drop.
(d) Shorten pipeline.
(e) Pressurize the supply tank, raise the supply tank, or lower the pump to increase suction line pressure.
(f) Heat the liquid being pumped to lower viscosity.
(g) Chill the liquid being pumped to lower vapor pressure.

b. Accessory Selection

The major accessories selected for use with controlled-volume pumps are pulsation-dampeners and back-pressure and relief-valves, and will be discussed here. Many other accessories may be used as well, including sulfuric acid sludge-traps, strainers, foot-valves and variable-speed drives. Most pump manufacturers offer a wide range of these items and can assist in sizing, installation, and other technical issues.

(1) Pulsation-Dampeners

Most designs consist of a pressure-vessel containing a flexible, elastomeric bladder which separates pressurized gas in the upper chamber from liquid being pumped in the lower chamber (Figure 8). In the most common application, surges from the pump output enter the dampener and instantaneously absorbed by the gas due to its inherent compressibility. the gas is precharged to a lower pressure than pump outlet pressure.

When used on the suction side of the pump to achieve constant velocity in the suction line, the dampener should be mounted in an inverted position to maintain a primed liquid chamber. When the pump is on discharge, the weight of liquid will deflect the bladder downward. When pump is on suction, energy stored in the compressed gas will push liquid from the dampener, reducing the required flow in the suction line.

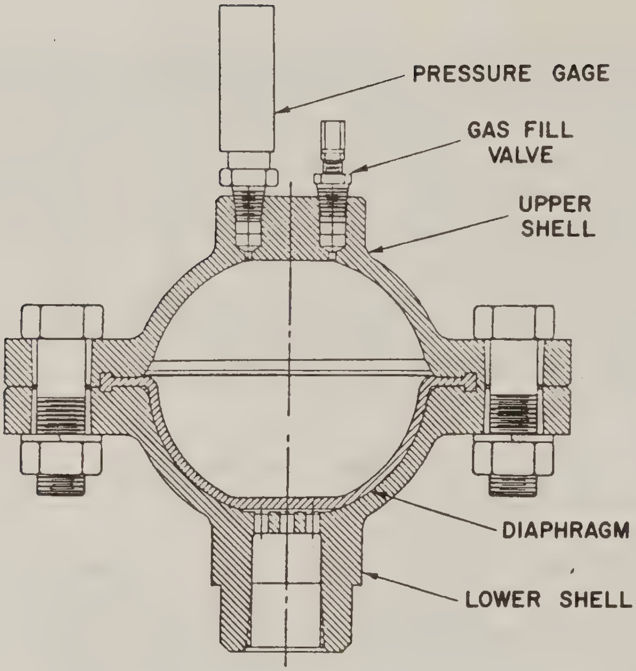

Figure 8. Typical Pulsation-Dampener.

A pulsation-dampener employs Boyle's Law as an operating principle; i.e., the volume of a given quantity of gas varies inversely with the pressure to which the gas is subjected, at constant temperature.

(2) Back Pressure and Safety Valves

Back-pressure valves (Figure 9) are anti-siphon devices used in controlled-volume pumping systems where the pressure in the system (irrigation line) is lower than the suction pressure at the pump inlet.

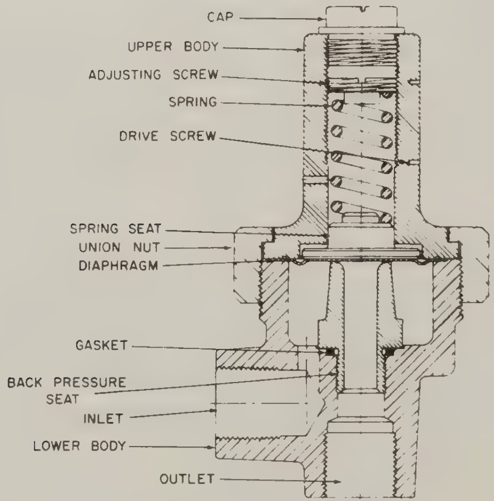

Figure 9. Typical Back-Pressure Valve.

A back-pressure valve maintains a pressure-head on the discharge of the pump, which is greater than the suction pressure, so that the liquid being pumped can be metered into the low pressure system.

The valve should be installed close to the injection point to optimize response time, an important factor in closed-loop control systems. Also, the use of a pulsation-dampener in conjunction with a back-pressure valve eliminates open-close cycling and resultant valve wear.

Safety valves prevent serious damage to pumps and discharge lines due to excess pressure brought about by an obstruction in the system (Figure 10). It should be noted, however, that internal relief-valves in hydraulically balanced diaphragm pumps are adequate to prevent system damage if the controlled-volume pump is the only source of pressure in the system.

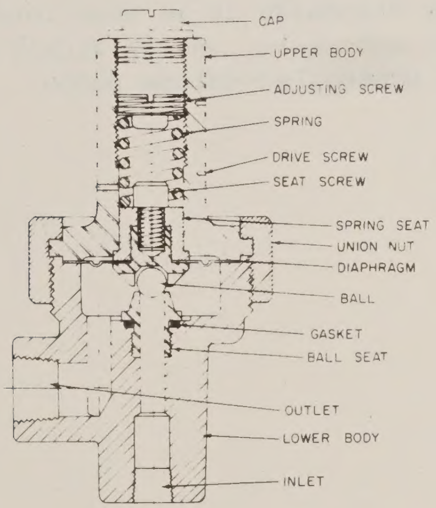

Figure 10. Typical Safety Valve.

Safety valves should be installed to vent or discharge into the supply tank above the maximum liquid level rather than into pump suction lines. Leakage can then be visually detected and, in the event of an overpressure condition, liquid will not be forced into the tank outlet, causing possibly hazardous turbulence.

Both the back-pressure and safety-valves are adjustable so that they can be tuned to the requirements of a given system.

4. Role of American Petroleum Institute (API) 675, Hydraulic Institute Standards

API Standard 675 is intended for use as an aid in the procurement of controlled-volume pumps for petroleum refinery services. The standard is based on accumulated knowledge and experience of both manufacturers and users, and will help insure the purchase of a rugged, industrial-duty pump that meets the generally rigorous equipment requirements of the API provided by a manufacturer. The Standard deals with all aspects of a comprehensive procurement specification, including equipment design, inspection and testing, guarantee and warranty, and software requirements. Many U.S. and foreign users in both refinery and non-refinery applications refer to API 675 standard to guarantee pump performance and quality.

Hydraulic Institute Standards is published by a pump manufacterers' trade association for the purpose of eliminating misunderstandings between the manufacturer and the purchaser, and to assist buyers in selecting the correct pump. The section dealing with controlled-volume pumps is based on work done by a technical committee of engineers specializing in such pumps, and encompasses a discussion of types, nomenclature, ratings, test standards, applications, installation and troubleshooting.

Hydraulic Institute Standards is an excellent source of technical information for specifiers and users, and is widely used as a reference in most industries employing controlled-volume pumps.